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Molybdenum Availability—Market Economy Countries

A Minerals Availability Appraisal

By C. M. Palencia

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES 75TH ANNIVERSARY

Information Circular 9044

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UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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PREFACE

The Bureau of Mines is assessing the worldwide availability of critical minerals, exclusive of the energy fuel minerals. The Bureau identifies, collects, compiles, and evaluates specific information on producing, developing, and explored mines and deposits, including the processing plants that convert raw minerals to marketable products. The objectives are to classify domestic and foreign resources in order to identify by cost evaluation those that are reserves, and to prepare analyses of the availability of these minerals at different times and conditions.

This report on the availability of molybdenum is part of a continuing series of reports that analyze the availability of critical minerals from domestic and foreign sources. Analyses of other minerals are currently in progress. Questions about these reports should be addressed to Chief, Division of Minerals Availability, Bureau of Mines, 2401 E St., NW., Washington DC 20241.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°F	degree Fahrenheit	mm	millimeter
h	hour	mt	metric ton
in	inch	mt/d	metric ton per day
km	kilometer	mt/yr	metric ton per year
lb	pound	pct	percent
lb/yr	pound per year	ppm	part per million
m	meter	yr	year

MOLYBDENUM AVAILABILITY—MARKET ECONOMY COUNTRIES

A Minerals Availability Appraisal

By C. M. Palencia[1]

ABSTRACT

The Bureau of Mines evaluated the potential availability of molybdenum resources from 88 mines and deposits that account for more than 90 pct of the demonstrated resource base in market economy countries (MEC's). For each property, tonnage-cost relationships were developed that indicate the molybdenum potentially available at different average production costs, including a 15-pct rate of return on invested capital. From the 23 MEC primary deposits, 2.5 billion lb Mo was determined to be potentially available at a price of $4/lb, rising to 4.7 billion lb Mo at $8/lb.

Copper price-molybdenum tonnage relationships were developed for those mines and deposits from which molybdenum can be recovered as a byproduct of copper production. This analysis showed that another 3.4 billion lb Mo is potentially available based on a copper price of $0.75/lb, rising to 4.3 billion lb Mo at $1.00/lb.

The United States has been the world's largest molybdenum supplier since 1924. Its remaining resources are sufficient to meet the domestic demand of 57 million lb/yr Mo (averaged for a 10-yr period) through the end of the century. Production from primary domestic mines was suspended during most of 1983 because of oversupply of materials. A major concern is the cheap molybdenum byproducts from foreign copper operations in which employment and the need for hard currency override economics in meeting production goals.

[1] Physical scientist (mining engineer), Minerals Availability Field Office, Bureau of Mines, Denver, CO.

INTRODUCTION

This study provides analyses of the resources, engineering, economics, and other factors that influence the availability of molybdenum. Production costs, including mining and beneficiation, were determined for each property. Since some producers market molybdenite concentrate as a final product at the minesite, no attempt was made to analyze factors affecting the availability beyond that point.

The molybdenum resources located in the Soviet Union, China, and other centrally planned economy countries (CPEC's) were not analyzed in this study. Inasmuch as it is difficult to collect quantitative resource information and production cost estimates from these countries, reliable and definitive estimates could not be developed.

Domestic deposits were evaluated by personnel of the Bureau's Field Operations Centers, and foreign data collection and cost estimation were performed under contract by Pincock, Allen and Holt Inc., Tucson, AZ; personnel of the Bureau's Minerals Availability Field Office, Denver, CO, evaluated the data and performed the economic evaluation analyses.

MOLYBDENUM PRODUCTS AND USES

A rare metallic element, molybdenum is gaining importance in industrial applications. In a pure state, molybdenum is a lustrous gray metal with a melting temperature of 4,730° F. The word molybdenum came from the ancient Greek word Molybdos, which means "leadlike," a name applied to all minerals that were soft and leadlike in character, probably minerals such as molybdenite, galena, and graphite. In 1778, Karl Wilhelm Scheele differentiated molybdenite from the other soft minerals. Four years later, J. J. Hjelm isolated the metal as a new element now known as molybdenum ("moly" for short).

It took more than a century to find a use for the new element. The French first applied molybdenum to toughen steel used in armor plates. Later the Germans improved the technology by using molybdenum as an alloying element with other metals. Further research found more applications for molybdenum including lubricants, paints, pigments, fertilizer additives, chemical catalysts, vitamin supplements, flame retardants, smoke suppressants, refractory metals, and semiconductor applications.

In spite of these diverse uses, 83 pct of molybdenum consumption is for alloying uses. In some stainless steels, molybdenum tends to minimize surface and intergranular corrosion. Figure 1 shows an approximate percentage consumption in market economy countries (MEC's) according to use for 1983 (*1*)[2].

[2] Italicized numbers in parentheses refer to items in the list of references preceding the appendix.

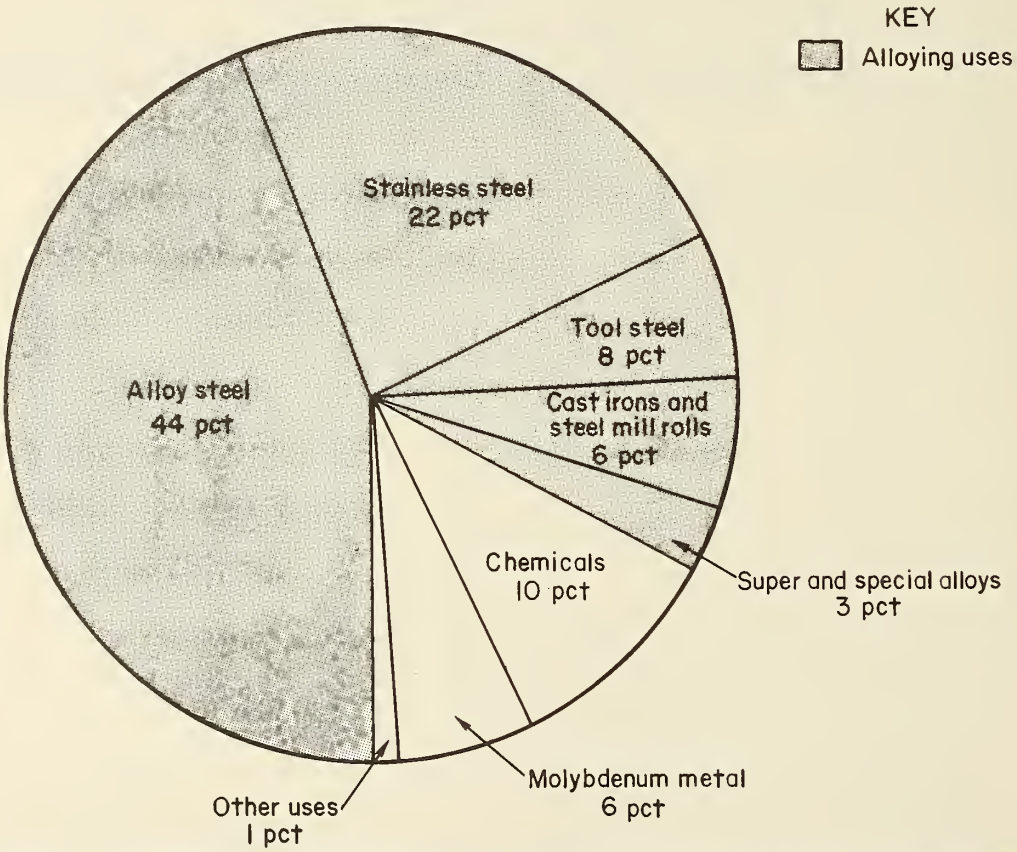

Figure 1—Molybdenum consumption according to industrial use, market economy countries, 1983.

Basically, nonintegrated mine operations (mostly small and byproduct producers) sell molybdenum in concentrate form to independent companies for roasting. The major portion of the total concentrate production is roasted to technical-grade molybdenum trioxide (MoO_3), the intermediate marketable material from which almost all molybdenum products are made; a small portion of the concentrate is used directly in mineral form (MoS_2). Any technical-grade oxide not directly used in the industry is further processed into another marketable form; i.e., high-purity MoO_3 and ferromolybdenum. The high-purity MoO_3 in turn is converted either into chemical form (as pure salts), metal form, or alloy form (as master alloys for high-temperature metals).

MARKETING AND PRICING STRUCTURE

There are two price structures in molybdenum markets, the producers' price and the dealers' price. Molybdenum marketed directly by producers is sold at the producers' price. Normally, this accounts for about 90 pct of total molybdenum production. The remainder is sold at a dealers' price in the open market; this often commands a premium in times of tight supply but sells at a discount in times of plenty. In 1979, when molybdenum demand was high and supply was tight, the dealers' price went up to more than twice the producers' price. However, when demand softened from mid-1980 through 1981, the dealers' price went down to as much as $3/lb below the producers' price. Table 1 provides price comparisons for the various forms of molybdenum from 1975 to 1983.

Molybdenum on the domestic market is almost all sold in processed forms; i.e., oxides, ferromolybdenum, and ammonium and sodium molybdate. Molybdenite (molybdenum sulfide in concentrate), if any, is sold in very small quantities for special uses such as lubricants. However, because of protective tariffs on processed molybdenum products, the molybdenum market overseas, especially in Western European countries, is mostly in the form of molybdenite concentrates. While the United Kingdom, France, Italy, and West Germany, for example, have no tariffs on molybdenite, they impose 25 pct, 9 pct, 7.5 pct, and 7 pct tariffs, respectively, on ferromolybdenum (*2*).

With the exception of 1977, molybdenum consumption in MEC's exceeded its production from 1974 through 1979. Consumption started declining in 1980 owing to the effects of the recession. In 1974, consumption exceeded production by about 42 million lb Mo. To offset demand requirements, the General Services Administration (GSA) released 35 million lb from the U.S. Government Stockpile (*3*). With strong demand continuing in September 1976 the GSA released all the remaining molybdenum concentrate from the Stockpile (*4*). The continued increase in consumption in 1978 and 1979, which far exceeded production, forced a drawdown from producers' inventories. This expanded industrial demand, combined with the supply shortage situation caused by labor strikes in Canada and reduced molybdenum byproduct recovery from copper production, resulted in an artificially high price in 1979 and early 1980, especially in the international market. A self-imposed, anti-inflationary measure instituted by the major domestic producers during these years kept domestic molybdenum prices well below those of exported products. (See table 1.) As production increased and consumption dropped in late 1980, the supply-demand picture took a reverse trend.

During the first quarter of 1981, while producers held the prices for technical molybdic oxides and ferromolybdenum at $9.70 to $9.35 and $10.60 to $10.25 per pound of contained molybdenum, respectively, dealers were selling the metal for about $1.25/lb lower. The price gap widened to about $3/lb in the last quarter (*5*). This price difference caused the producers to follow the downward trend, and in December 1981 Codelco (the Government-owned Chilean copper producer) posted a price per pound of $5.55 for oxide and $6.55 for ferromolybdenum. In early 1982, a wide difference in prices existed between individual producers. While Climax held to its published price of $8.75 for canned oxide, $9.90 for ferromolybdenum, and $8.80 for briquettes, Codelco posted prices of $5.52 for oxide, $6.57 for ferromolybdenum, and $5.61 for briquettes. At the same time, Duval and Noranda quoted export prices of $7.00 for oxides, $8.10 for ferromolybdenum, and $7.11 for briquettes. Dealers' prices for this period ranged from $4.80 to $5.15 for oxide and $5.15 to $5.50 for ferromolybdenum. In September 1982, Climax firmed the price at $5.85 for oxide, $6.75 for fer-

Table 1.—Comparative prices of molybdenum products

(Dollars per pound of contained molybdenum)

	Concentrates		Technical-grade oxide		Ferromolybdenum	
Year	Byproduct	Climax	Climax[1]	Dealers	Climax lump	Dealers' export
1975	$ 2.20- $2.62	$2.62	$2.90	$2.90- $2.95	$3.44	$3.45- $3.50
1976	2.85- 3.20	2.70	3.54	3.30- 3.35	4.10	3.80- 3.90
1977	3.85- 4.01	4.01	4.31	3.60- 3.75	4.99	5.40- 5.80
1978	4.50- 5.15	4.95	5.30	9.00- 9.50	6.10	9.75- 10.00
1979	25.00- 27.00	8.84	9.80	26.00- 28.00	6.68	29.00- 29.50
1980	7.50- 9.00	9.20	9.70	6.95- 7.45	9.90	8.60- 9.30
1981	5.80- 7.90	7.90	8.50	6.65- 6.25	9.40	7.30- 8.00
1982	3.10- 3.50	7.90	8.50	4.30- 4.60	9.40	5.35- 5.55
1983	3.30- 3.60	[2]	[2]	3.75- 4.05	[2]	4.45- 4.55

[1]The Climax oxide prices shown are for domestic consumption. The oxide export prices were as follows:

1980 ....$21.50-$22.49 1982 ....$11.15-$13.23

1981 ....$18.50-$19.29 1983 ....$ 8.65-$13.23

[2]Suspended.

Source: Metals Week, various years.

romolybdenum, and $5.96 for briquettes. Simultaneously, Codelco lowered its price for oxide to $4.50/lb, while the dealers sold the material for as low as $2.50/lb (*6*).

In December 1982, the average dealers' price for oxide slipped to $2.47/lb Mo. Low price, compounded by high inventory and sluggish demand for the metal, caused primary producers to stop mine production for most of 1983; the only new molybdenite supply at the time came from byproduct producers. This limited supply of molybdenite induced the drawdown of inventories and eventually resulted in an upturn of price. Although there was no reported producers' price in 1983, dealers' price for oxide ranged from $3.75/lb to $4.05/lb Mo for most of the year (*1*).

WORLD PRODUCTION, CONSUMPTION, AND TRADE

Since the reopening of the Climax Mine in 1924, the United States has maintained its position as the world's largest molybdenum producer. A net exporter, the United States supplies not only MEC's, but also CPEC's. Molybdenum production in MEC's over the last 10 yr averaged 178 million lb, with the United States accounting for 63 pct of the total, or 114 million lb/yr (table 2). Consumption from MEC production over the last 10 yr averaged 148 million lb/yr with the United States using 57 million lb/yr (table 3). This indicates that more than half of U.S. production is exported, as is a large portion of the production from Canada and Chile.

China, the U.S.S.R., and other CPEC's, as shown in table 2, produced an estimated 34 million lb in 1982. Nevertheless, these countries as a whole are net importers of molybdenum. As a block these countries imported an average of 17 million lb/yr from 1974 through 1982 (table 3).

International trade is primarily limited to molybdenite, especially in Western European countries because of protective tafiffs imposed on processed molybdenum forms. In order to directly enter the European market, AMAX Inc. (the U.S.'s largest producer) established processing plants in the Netherlands, England, and Italy.

Although molybdenum enters international trade in the form of molybdenite concentrate and various primary products, prices are based on the molybdenum content of the product. Normally, molybdenite is marketed at a minimum grade of 90 pct MoS_2; however, molybdenum produced as a byproduct may be marketed at a lower MoS_2 grade.

To protect domestic molybdenum producers, the United

Table 2.—Molybdenum production from market economy and centrally planned economy countries

(Million pounds of contained molybdenum)

Country	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
MEC's:										
United States	112	106	113	122	132	144	151	140	83	34
Canada	29	32	31	33	31	25	26	31	31	23
Chile	21	23	24	24	29	30	30	34	44	33
Mexico	[1]	[1]	[1]	[1]	[1]	[1]	[1]	1	11	13
Peru	1	1	1	1	2	3	6	7	7	6
Total	163	162	169	180	194	202	213	213	176	109
CPEC's:										
China	0	0	3	3	4	4	4	4	4	4
U.S.S.R.	20	20	20	21	21	22	22	23	24	24
Others	0	0	1	1	1	1	1	1	6	6
Total[2]	20	20	24	25	26	27	27	28	34	34
Grand total	183	182	193	205	220	229	240	241	210	143

p Prelimary.
[1]Less than 170,000 lb.
[2]Bulgaria, Mongolia, Niger , North Korea, Romania, Turkey, and Yugolslavia are believed to have molybdenum production, but no quantitative output information is available.
Sources: Engineering and Mining Journal and Bureau of Mines Mineral Industry Surveys, various years.

Table 3.—Molybdenum consumption from production in market economy countries

(Million pounds of contained molybdenum)

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983[p]
MEC's:										
United States	75	55	57	60	69	71	60	58	34	30
Western Europe[e]	78	66	70	70	72	75	65	57	55	53
Japan	27	21	25	24	25	25	28	26	26	24
Subtotal	180	142	152	154	166	171	153	141	115	107
CPEC's[e]	14	15	15	17	22	22	18	18	15	18
Other	13	11	10	11	12	12	11	11	9	8
Subtotal	27	26	25	28	34	34	29	29	24	26
Total	207	168	177	182	200	205	182	170	139	133

e estimated. P preliminary.
[1]Production data include both Government and private shipment and releases from inventory stockpile.
Source: Engineering and Mining Journal, various years.

States also imposed a restrictive tariff schedule on most molybdenum products, especially those coming from countries not having a most-favored-nation (MFN) status. In 1979, a multilateral trade negotiation, known as the Tokyo Round, adopted new tariff agreements that placed most countries under the MFN status and gave them a much lower tariff rate. The agreement called for the phasing down of tariff rates for MFN countries over a 7-yr period ending in 1987 (*7*). This two-tiered tariff schedule is shown in table 4.

Table 4.—U.S. import duties on molybdenum materials

(Percent ad valorem, except where indicated)

Material	Most-favored-nation (MFN) Jan. 1, 1983	Most-favored-nation (MFN) Jan. 1, 1987	Non-MFN: Jan. 1983
Ore and concentrate, ¢/lb	10.5	9.0	35.0
Material in chief value molybdenum ....¢/lb	8.0	6.0	50.0
Plus pct ad valorem	2.5	1.9	5.0
Ferromolybdenum	5.9	4.5	31.5
Molybdenum:			
Waste and scrap	8.3	6.0	50.0
Wrought	9.6	6.6	60.0
Unwrought .....¢/lb	8.1	6.3	50.0
Plus pct ad valorem	2.5	1.9	15.0
Molybdenum chemicals:			
Ammonium molybdate	5.3	4.3	29.0
Calcium molybdate	4.8	4.7	24.5
Molybdenum compounds	3.7	3.2	20.5
Potassium molybdate	3.4	3.0	23.0
Sodium molybdate	4.4	3.7	25.5
Mixtures of inorganic compounds, chief value molybdenum	3.2	2.8	18.0
Molybdenum orange	5.0	5.0	25.0

Source: Blossom (*7*).

U.S. PRODUCTION, CONSUMPTION, AND TRADE

Table 5 shows production, shipments, and stocks of molybdenum in concentrate for U.S. producers. Shipments alone may not represent the actual mine production volume, since some molybdenum produced in a specific year may be shipped or released from the mine stockpile. The shipment statistics shown may be a little confusing; while the export figures are actual concentrate shipments to foreign countries, the domestic shipments of concentrate may not to used for domestic consumption per se. Domestic shipments, in part, represent deliveries of concentrate to intermediate processors or converters, who in turn may export finished molybdenum products. In addition, domestic consumption is not always the difference between the domestic production and foreign exports, since producers normally keep or release inventories depending on the status of supply and demand prevailing at the time. Total U.S. exports of molybdenum in all forms are shown in table 6.

U.S. export destinations vary from year to year, though the major importing countries are the Netherlands, Japan, Belgian-Luxembourg, and the Federal Republic of Germany. Most of the concentrate exported is converted to oxides and reshipped to other countries, including CPEC's.

Imports account for 2 to 5 pct of domestic U.S. consumption. The majority of imports are in the form of concentrate, primarily from Canada. Other sources of U.S. imports include China, a supplier of ammonium molybdate, Japan, Peru, and Western European countries.

Table 5.—U.S. salient molybdenum concentrate statistics

(Thousand pounds of contained molybdenum)

Item	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Production	112,011	105,980	113,233	122,408	131,843	143,967	150,686	139,900	83,050	33,951
Shipments[1]:										
Domestic[2]	78,198	68,552	83,592	95,308	99,511	107,099	114,285	86,182	55,918	39,822
Export	39,965	36,618	30,935	29,666	31,183	36,405	35,026	32,734	21,870	9,341
Stocks, mine and plant	18,659	10,680	9,390	9,161	8,980	9,520	18,101	35,548	35,527	36,407

[1]As reported by producers.
[2]Part of domestic shipment is exported in molybdenum product forms.

Table 6.—U.S. molybdenum exports as reported by producers

(Thousand pounds of contained molybdenum)

Item	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Molybdenite concentrate	39,965	36,618	30,935	29,666	31,183	36,405	35,026	32,734	21,870	9,341
Molybdic oxide	35,949	31,210	29,644	31,529	33,258	33,920	33,167	19,072	22,938	18,847
Others	2,921	1,874	2,152	1,803	2,095	1,853	2,390	932	437	839
Total	78,835	69,702	62,731	62,998	66,536	72,178	70,583	52,738	45,245	29,027

GEOLOGY

Molybdenum deposits are classified into five genetic types: (1) primary porphyry or disseminated deposits, including stockworks and breccia pipes in which metallic sulfides are dispersed through relatively large volumes of altered and fractured rocks; (2) contact metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive granitic rocks; (3) quartz veins; (4) pegmatites and aplite dikes; and (5) bedded deposits in sedimentary rocks (*8*).

The first three genetic types are determined to be hydrothermal in origin. As such, nearly all resources in the world fall under these types. The remaining two types currently do not possess any economic importance. Molybdenum from these types are recovered only when it interferes in the metallurgical recovery of the primary product (*8*).

Primary porphyry deposits, the major source of molybdenite, occur as small disseminated grains in veins and veinlets of hydrothermally altered igneous rocks. The mineralization normally is associated with intrusions along fault intersections. Generally, the intrusive rocks are siliceous with composition ranging from granodiorite to granite.

The average mineral concentration in the resources identified for this study ranges from 0.1 to 0.5 pct MoS_2. The major known deposits of this type are the Endako and Boss Mountain Mines of Canada, and the Climax, Henderson, and Mount Tolman deposits of the United States.

Copper-molybdenum porphyry deposits are somewhat similar in origin to that of primary molybdenum porphyry deposits. The deposits are related to silicic intrusions and hydrothermal alteration. Molybdenite concentrations are much lower, ranging from 0.015 to 0.1 pct MoS_2, and therefore can only be economically recovered as a byproduct (*9*).

In contact-metamorphic and tactite deposits, molybdenite is widely distributed along the contact between granitic intrusives and lime-rich sedimentary rocks. In many places, the size, shape, and occurrence of the ore bodies indicate that the mineralization was controlled by preore fracturing of the lime-rich host rock. The molybdenite is usually associated with scheelite, bismuthite, and copper sulfides. The deposits are generally small, but contain relatively high molybdenite concentration, up to 0.6 pct MoS_2. The only domestic molybdenite production from this type of depost was a byproduct from the Pine Creek tungsten mine in California (*10*).

Molybdenite also occurs in fissure or quartz vein deposits. The vein filling is mainly quartz and molybdenite with minor amounts of pyrite, chalcopyrite, and chlorite and varies in size from a fraction of an inch to several feet. The mineral concentration also varies widely, and most of the molybdenite is fairly fine grained and appears to be concentrated along vein walls or joints and seams. The Questa surface mine in New Mexico is the only deposit known to have produced appreciable amounts of molybdenite from this type of deposit.

Pegmatite and aplite dike deposits are igneous rocks that were formed by magmatic fluid filling dikes with rock composition similar to that of the associated pluton. Molybdenite generally occurs in coarse crystalline structure, forming large rosettes and aggregates of flakes, which are valued as a mineral specimen rather than as a source of molybdenum. Mineralization normally occurs in small pods that give no leads to other pods and limit mining to single pods. Very few deposits of this type have been developed. Known deposits include the Val d'Or and Preissac deposits of Quebec, Canada (*8*).

Molybdenite is also found in bedded sedimentary rocks like coal and shale, though the concentrations are too low to be of economic importance. In some lignitic sandstone deposits of Montana, the Dakotas, and Utah, the mineral approaches economic concentrations. Some molybdenite minerals are also associated with bedded uranium in Arizona, Wyoming, South Dakota, New Mexico, and Utah. In such deposits, when the mineral reaches a high level of concentration, it becomes necessary to separate the molybdenite as it interferes with uranium recovery (*9*).

MINERALOGY

Molybdenum has not been found free or as a native metal in a natural environment. Even as a compound, it is relatively scarce, comprising only about 1.0 to 1.5 ppm concentration in the continental crust. This concentration is evenly distributed throughout igneous rocks, though higher concentrations have been noted in basalt rocks.

Molybdenite (MoS_2) and, to a minor extent, wulfenite ($PbMoO_4$), powellite [$Ca(Mo,W)O_4$], and ferrimolybdite [$Fe_2(MoO_4)_3.8H_2O$], are the most important minerals of molybdenum. Table 7 summarizes the physical and chemical properties of these principal minerals. Powellite and fer-

Table 7.—Physical and chemical properties of principal molybdenum minerals (*10*)

Properties	Molybdenite	Wulfenite	Powellite	Ferrimolybdite
Composition	MoS_2	$PbMoO_4$	$Ca(Mo,W)O_4$	$Fe_2(MoO_4)_3 \cdot 8H_2O$.
Mo pct	60.0	26.1	39-48	39.
Crystal system	Hexagonal	Tetragonal	Tetragonal	Orthorombic.
Cleavage	Perfect in 1 direction	Perfect in 4 directions	Indistinct	NA.
Sp. gr.	4.6-4.7	6.5-7.0	4.3	2.99-4.5.
Color	Lead-gray	Grayish-white through yellow to orange and orange red.	Straw yellow to dirty white.	Sulfur yellow.
Tenacity	Flexible	Brittle	NA	Powdery.
Luster	Metallic	Adamantine or resinous	Subadamatine, pearly, or greasy.	Silky to earthy.
Fracture	None	Uneven	Uneven	None.
Hardness[1]	1-1.5	3	3.5-4	1.5.
Streak	Bluish gray on paper, greenish on porcelain or glazed paper.	White	White	Pale yellow.

NA Not available.
[1]Mohs scale.

rimolybdite, which are products of oxidation from other minerals, have widespread occurrences, though it is unlikely that they will become major sources of molybdenum.

Molybdenite is the most common mineral of molybdenum. The mineral is lead-gray with a metallic sheen that characteristically occurs in thin, tabular, hexagonal plates, and is disseminated in fine specks. The plates have an eminent basal cleavage, and are soft and flexible but not elastic. Molybdenite is commonly mistaken for graphite because of its similarity in structure and softness. It frequently occurs in pneumatolytic contact deposits associated with cassiterite, scheelite, wolframite, fluorite, etc.

Wulfenite, a lead molybdate, is a heavy mineral with a resinous or adamantine luster. The mineral occurs in a well-formed crystal structure, commonly square tabular, but sometimes extremely thin. It displays a very smooth cleavage with red, orange, yellow, gray, and white colors. Wulfenite is of secondary origin, being found in lead and zinc deposits in the oxidation zone (*11*).

Powellite, a calcium molybdate with calcium tungsten, is formed through the oxidation of molybdenite. The mineral is powdery and exhibits a tetragonal crystal structure with variable colors, including dirty white, straw yellow, greenish yellow, pale green, blue, and brown. Powellite is isomorphous and often associated with scheelite. This association helps in the identification of powellite because it fluoresces a golden yelllow color under ultraviolet light (*11*).

Ferrimolybdite, long known as "molybdite," is a hydrous ferric molybdate. The mineral is commonly impure and most often is intimately associated with limonite. The mineral is soft with a distinctive canary yellow color. It occurs commonly in small amounts as an oxidation product of molybdenite.

Other molybdenum minerals include chillagite, ilsemannite, koechlinite, lingrenite, achrematite, belonisite, eosite, and jordisite (*12*).

RESOURCES

A total of 88 primary and byproduct properties in MEC's were evaluated to determine potential reserve-resources, grade, mine capacity, and costs of production. The 23 primary properties consisted of 9 producing mines and 14 undeveloped deposits. The 65 secondary properties (in which molybdenum is produced as a byproduct of copper production) consisted of 34 producing and 31 undeveloped deposits. Deposit locations are shown in figure 2. Discussion of the geology of individual primary deposits is included in the appendix.

MEC primary molybdenum properties have approximately 5,018 million mt of in situ ore, containing 9.6 billion lb of recoverable molybdenum and are all located in North America (table 8). Nearly 84 pct of the recoverable molybdenum would be from U.S. deposits, with Canada and Mexico accounting for 13 pct and 3 pct, respectively.

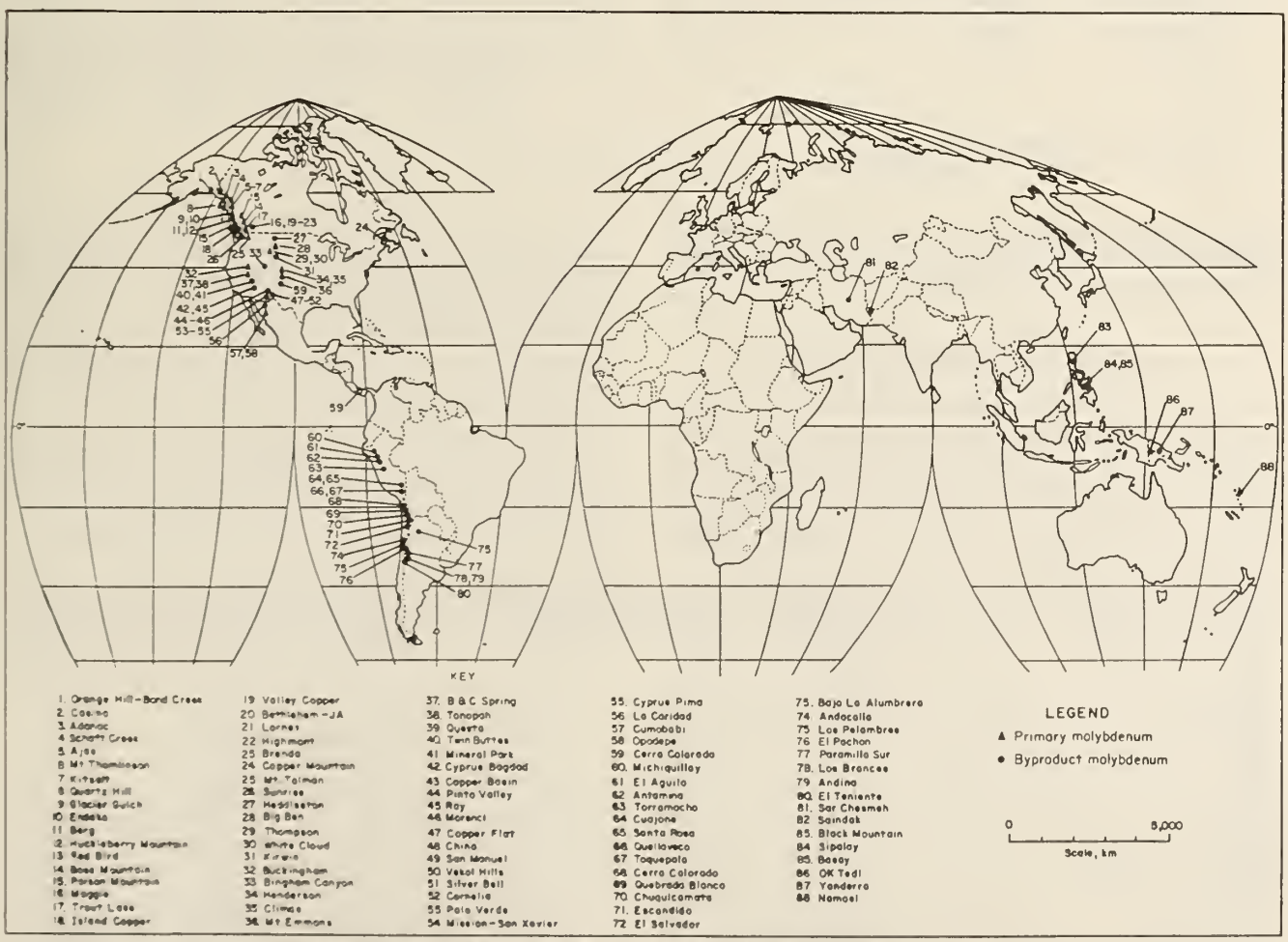

Figure 2.—Molybdenum deposit locations, market economy countries.

Table 8.—Primary molybdenum deposits and in situ demonstrated resources, market economy countries, January 1983

Country and deposit name	Owner	Status[1]	Type[2]	Demonstrated resources, 10^6 mt	Grade pct Mo	Recoverable Mo in conc, 10^6 mt	Estimated ore capacity 10^3 mt/yr
Canada:							
Adanac	Adanac Mining & Explorations Co.	E	S	201	0.059	229	4,760
Ajax Deposit	Newmont Mining Corp.	E	U	179	.073	205	8,750
Boss Mountain	Noranda Mines Ltd.	P	C	4	.141	9	857
Endako	Placer Development Co.	P	S	187	.095	305	10,320
Glacier Gulch	AMAX Inc.	E	U	18	.210	57	1,050
Kitsault	..Do	P	S	104	.112	232	3,810
Mt. Thomlinson	Kidd Creek Mines Ltd.	E	U	41	.072	44	2,493
Red Bird	Phelps Dodge Corp. of Canada	E	S	81	.071	102	3,500
Trout Lake	Newmont, 55 pct; ESSO, 45 pct	E	U	49	.115	85	2,600
Subtotal				864	.084	1,268	38,140
Mexico:							
Cumobabi	Minera Cumobabi S.A. de C.V.	P	S	17	.250	67	7,000
Opodepe	Compania Minera Fresnillo, S.A.	E	S	162	.100	241	7,000
Subtotal				179	.114	308	14,000
United States:							
Big Ben Deposit	AMAX Inc.	E	S	107	.096	187	5,350
Buckingham Deposit	Rocky Mt. Energy	E	S	217	.057	224	7,000
B&C Spring	Sharon Steel	E	S	34	.080	47	2,198
Climax Mines	AMAX Inc.	P	C	375	.210	1,397	17,123
Hall (Tonopah) Mine	Anaconda Co.	P	S	143	.096	303	7,000
Henderson Mines	AMAX Inc.	P	U	223	.251	999	9,710
Mt. Emmons	..do	E	U	115	.323	678	6,602
Mt. Tolman	Colville Confederated Tribe	E	S	900	.060	953	19,050
Quartz Hill	Pacific Coast Molybdenum Co.	D	S	1,362	.082	2,112	19,591
Questa Mines	Molycorp	P	U	95	.186	395	5,877
Thompson Creek	Cyprus Mine Corp.	P	S	175	.112	389	8,051
White Cloud	ASARCO	E	S	229	.081	368	7,938
Subtotal				3,975	.109	8,052	115,510
Total				5,018	.109	9,628	167,650

[1]P Producer; D Developing; E Explored.
[2]S Surface; U Underground; C Combined.

The resource from byproduct properties as estimated at 30,535 million mt of ore, with recoverable molybdenum estimated at 6.8 billion lb (table 9).

Primary Molybdenum Resources

The United States has an estimated 8.0 billion lb of recoverable molybdenum from 12 primary mines. Five of these mines – Climax, Henderson, Thompson Creek, Hall, and Questa – were evaluated as producers, and one mine, Quartz Hill, was evaluated as developing property. The remaining six deposits have been explored but have no immediate plans for development. The present capacity from producing primary domestic deposits was estimated at 153 million lb/yr Mo; an additional capacity of 40 million lb/yr will be added when Quartz Hill starts production.

Canada accounts for 1.3 billion lb of recoverable molybdenum from nine primary deposits. Current production comes from three mines with an installed capacity estimated at 23 million lb/yr.

Mexico has two primary molybdenum deposits (a producer and a nonproducer), with total recoverable molybdenum estimated at 308 million lb. Molybdenum production from Cumobabi, the producing mine, is estimated at 2.7 million lb/yr, though a capacity expansion is being planned.

Table 9.—Byproduct molybdenum deposits and in situ demonstrated resources, market economy countries, January 1983

Country	Demonstrated resources, 10^6 mt	Av feed grade, pct		Recoverable Mo in conc, 10^6 lb	Estimated ore capacity, 10^3 mt/yr	
		Cu	Mo		Producer	Nonproducers
Argentina	1,279	0.73	0.014	244	0	37,569
Canada	3,250	.40	.033	873	73,918	61,836
Chile	11,050	1.32	.060	2,935	74,443	60,116
Fiji	813	.49	.014	73	0	14,200
Iran	414	1.13	.030	117	13,200	0
Mexico	1,200	.67	.020	317	25,200	0
Pakistan	348	.43	.006	14	0	3,500
Panama	1,380	.73	.009	172	0	27,000
Papua New Guinea	791	.81	.015	136	0	34,312
Peru	2,841	.87	.021	705	33,840	14,805
Philippines	879	.50	.002	25	22,600	0
United States	6,290	.62	.019	1,153	268,538	35,331
Total	30,535	.89	.034	6,764	511,739	288,669

Byproduct Molybdenum Resources

The 21 U.S. copper properties analyzed for this report have the capability to produce a total of 1.2 billion lb Mo from demonstrated resources. Of these deposits, 14 were evaluated as producers, though many are presently temporarily shut down. These 14 producing mines have the capacity to produce an estimated 47 million lb/yr Mo.

Canada has recoverable molybdenum estimated at 873 million lb from 13 copper deposits. At present, copper producers contribute about 21 million lb/yr Mo from 6 mines.

The La Caridad copper mine in Mexico has a recoverable molybdenum resource estimated at 317 million lb. Current capacity is estimated at 10.1 million lb/yr.

All molybdenum production in Chile is a byproduct of copper operations, with Chuquicamata and El Teniente accounting for more than 82 pct of the total. Chile has an estimated 2.9 billion lb Mo recoverable from 10 copper properties, 5 of which are producing. At present, the five producing mines have a total installed capacity estimated at 45 million lb/yr Mo. Actual capacity may vary depending on the grade and recovery at the time. For example, in 1982, one major mine not only improved the mill recovery but also encountered a high-grade molybdenum ore body, causing a large increase in molybdenum output in that particular year.

Molybenum resources in Peru come from eight copper deposits. Current production comes from four copper operations, with Cuajone and Toquepala accounting for more than 98 pct of the total. Demonstrated resources for the eight properties evaluated is estimated at 2.8 billion mt of ore and 705 million lb Mo (recoverable). The installed capacity from the four producing mines is estimated at 9.0 million lb/yr.

Iran has a single source of molybdenum, the Sar Cheshmeh copper mine. The mine has an estimated reserve of 414 million mt ore, containing approximately 117 million lb Mo (recoverable). The installed capacity of the mine is estimated at 4.0 million lb/yr.

Production of molybdenum in the Philippines comes from three small copper operations: Sipalay, Basay, and Black Mountain Mines. The total demonstrated resource from these mines is estimated at 879 millions mt containing a total of 25 million lb Mo (recoverable). The present installed capacity is approximately 1.0 million lb/yr.

Among countries with nonproducing deposits, Argentina accounts for the largest molybdenum in situ resources with 1,279 million mt ore from Bajo la Alumbrera, Paramillo Sur, and El Pachon deposits. The recoverable resource from these deposits is estimated at 244 million lb Mo, all of which would be recovered as a byproduct of copper operations. Fiji has one copper deposit, the Namosi, with in situ reserves estimated at 813 million mt ore. An estimated 73 million lb Mo is potentially recoverable. Pakistan also has one property, the Saindak Copper deposit, which contains an estimated 14.3 million lb Mo (recoverable).

One copper deposit in Panama contains molybdenum, the Cerro Colorado. An estimated 172 million lb Mo is potentially recoverable. Development of this deposit has been delayed because of the slumping copper market. Papua New Guinea has two deposits, the OK Tedi and Yanderra, from which about 137 million lb Mo is potentially recoverable. OK Tedi started initial production for gold in 1984. However, production of copper and molybdenum is not scheduled to start until 1987.

MINING AND PROCESSING TECHNOLOGY

MINING METHODS

Ore deposits are mined by either underground or open pit methods. The selection of a mining method for a given deposit is more or less controlled by the grade, size, shape, and attitude of the ore body. Normally, the ideal choice is the one that gives safe working conditions and yields the greatest economic profit. Since primary molybdenum deposits occur as low-grade, high-tonnage porphyry deposits, low-cost underground block-caving and open-bit operations are the most commonly used methods to extract the ore economically.

Currently, of the nine primarily molybdenum producers, two use underground block-caving methods (Henderson and Questa), five use open-pit methods (Endako, Kitsault, Cumobabi, Thompson Creek, and Hall), and two use combined methods (Climax and Boss Mountain). Of the byproduct operations, six are mined by underground block-caving methods and the rest by open pit.

BENEFICIATION

To separate the molybdenite from the gangue minerals, the ore is crushed and ground to a size where the mineral is liberated. The size requirement is controlled by the ore characteristics, economics, and available processing technology. Molybdenite is a relatively easily flotable mineral, so concentration always involves crushing and grinding to release the mineral, followed by floatation. Crushing of molybdenite ore, as practiced by primary molybdenum producers, consists of primary, secondary, and tertiary crushing systems. Semiautogenous crushing is practiced at the Henderson and Thompson mines where run-of-mine ore is crushed through the primary stage only to take advantage of the grinding effect of the rock size.

After crushing, the ore is fed to ball mills which are in closed circuit with classifiers. Most of the flotation reagents are added at the grinding stage. Final grinding is monitored closely to avoid the production of fines.

Molybdenite flotation practices are very similar for all operations. The only noticeable difference is in the equipment sizes, where newer plants employ much larger, more efficient equipment than old plants.

In normal flotation practice, the pulp is pumped through banks of rougher cells, to produce a rougher concentrate. This is then reground in closed circuit with a classifier and routed to the cleaner section. Generally three to four cleaner stages are required before a final concentrate is produced. The grade of the final concentrate is about 54 pct Mo (90 pct MoS_2).

In the Cu-Mo flotation process, the rougher cells are designed to handle bulk flotation at the highest overall recovery of copper and molybdenite minerals at the coarsest grind possible. A much stronger collector such as xanthate is used for bulk flotation in the rougher cells, and a more selective reagent is used in the cleaner cells. A nonselective frother is also used in the rougher cells, methylisobutyl carbinol (MIBC) being the most popular.

Copper-molybdenum separation varies from one plant to another, especially in the use of chemical reagents. However, the most commonly used technique to recover molybdenite

from copper is the sodium hydrosulfide-sodium sulfide process. In this process, sodium hydrosulfide or sodium sulfide is added to the copper-molybdenite concentrate in a flotation procedure to depress the copper and ion sulfide minerals and allow the molybdenite to float (*13*). Sometimes cooking or steaming is done ahead of the rougher flotation circuit to reduce sulfide consumption. Although the hydrosulfide process can treat all Cu-Mo concentrate separations, the economics of the process may vary. This is mainly because of varying concentrate composition, especially in terms of mineral contaminants. The presence of contaminants such as talc, coal, and sulfur alter the entire process.

OTHER PROCESSING

Molybdenite concentrate (90 to 95 pct MoS_2) is processed in roasters to produce technical-grade MoO_3. Roasting is normally performed in four-zone multiple-hearth roasters, where molybdenite is converted to technical-grade MoO_3 exothermically.

The first zone is for preheating, final drying, and burning of residual flotation oils. Temperature increases exothermically in the second zone, where the molybdenite is converted to MoO_2 with a minor amount transformed to MoO_3. In the third zone, both the remaining sulfide and dioxide are converted to MoO_3. In the fourth zone, with about 95 pct of the molybdenite already oxidized, an exothermic reaction can no longer be sustained. Hence, supplemental heat is supplied to complete the removal of sulfur to a content of less than 0.1 pct.

The product, technical-grade MoO_3, contains about 88 to 98 pct MoO_3. About 0.1 pct of the plant feed is lost in the dust.

Ferromolybdenum production begins by blending a charge consisting of MoO_3, ferrosilicon, and iron oxide to attain a homogenous mixture. A starter mix composed of magnesium, aluminum, potassium nitrate, and iron oxide is sprinkled over the charge and ignited; it readily ignites and starts the exothermic reaction. The reaction generates heat high enough to initiate the ignition of the actual charge. The resulting molten bath attains a temperature of 3,300° to 3,500° F in the final stage of the reaction. This is allowed to cool for at least 16 h. At this time, a metallic ferromolybdenum button is formed, and subsequently quenched.

The metallic button is allowed to cool for another 24 h, before the slag is separated from the ferromolybdenum metal. Following the smelting and cooling the ferromolybdenum metal is normally broken to minus 8-in size before it is crushed and screened to different sizes and specifications (*14*).

DEPOSIT EVALUATION PROCEDURE

Illustrated in figure 3 is the flow of the Bureau's Minerals Availability program (MAP) evaluation process, from deposit identification to the development of availability curves. This flowsheet shows the various evaluation stages used in this study to assess the availability of molybdenum from individual properties. After a deposit was identified for analysis, an economic evaluation of the property was performed. Optimal mining and concentrating rates and other production parameters were chosen using current engineering principles. Startup dates for developing deposits were based on announced company plans. For explored deposits, a near-term development schedule (5 to 10 yr) was developed. Planned expansions for operating mines were included when known.

Information on average grades, ore tonnages, and different physical characteristics affecting production was obtained from various sources, including Bureau of Mines and U.S. Geological Survey publications, professional journals, State and industry publications, company annual reports, 10K reports and prospectuses filed with the Securities and Exchange Commission, private companies, and estimates made by Bureau personnel. Much of the foreign data was collected through a Bureau contract with Pincock, Allen and Holt Inc., of Tucson, AZ.

Selection of deposits was limited to known deposits that have significant demonstrated reserves or resources. Reserves are material that can be mined, processed, and marketed at a profit under prevailing economic and technological conditions. Resources are concentrations of naturally occurring solid, liquid, or gaseous materials in the earth's crust in such form that economic extraction of a commodity is currently or potentially feasible (*15*).

For the deposits analyzed, tonnage estimates were made at the demonstrated resource level based on the mineral resource-reserve classification system developed jointly by the Bureau of Mines and the U.S. Geological Survey (*15*). The demonstrated resource category includes measured plus indicated tonnages (fig. 4). Generally, reserve and resource tonnage and grade calculations presented in this report were computed from specific measurements, samples, or production data, and from estimations made on geologic evidence.

The deposits included in the analysis had to meet the following criteria:

1. Producing properties accounting for at least 85 pct of the molybdenum production from each significant producing country.
2. Developing and explored deposits where the demonstrated molybdenum reserve-resource quantity was equivalent to at least the lower limits of the reserve-resource quantity of the producing deposits.
3. Past-producing deposits where the remaining demonstrated molybdenum reserve-resource quantity was equivalent to at least the lower limits of the reserve-resource quantity of the producing deposits.

ASSUMPTIONS

The objective of the engineering-economic analysis for each deposit was to determine the total cost necessary to produce a specified level of output from the deposit. Total cost, also called commodity or incentive price, is defined as the average total cost of production for the deposit. In this study, profit computed at a 15-pct discounted-cash-flow rate of return (DCFROR) was included in the total cost. Total cost, then, is the minimum molybdenum price (in constant dollars) at which a firm would be willing to develop its property; at this price, the firm would recover its investment and make a 15-pct profit.

Determinations of the quantity of molybdenum that could be produced and the cost required to achieve this production were based on the following assumptions:

1. Each operation will produce at full planned operating

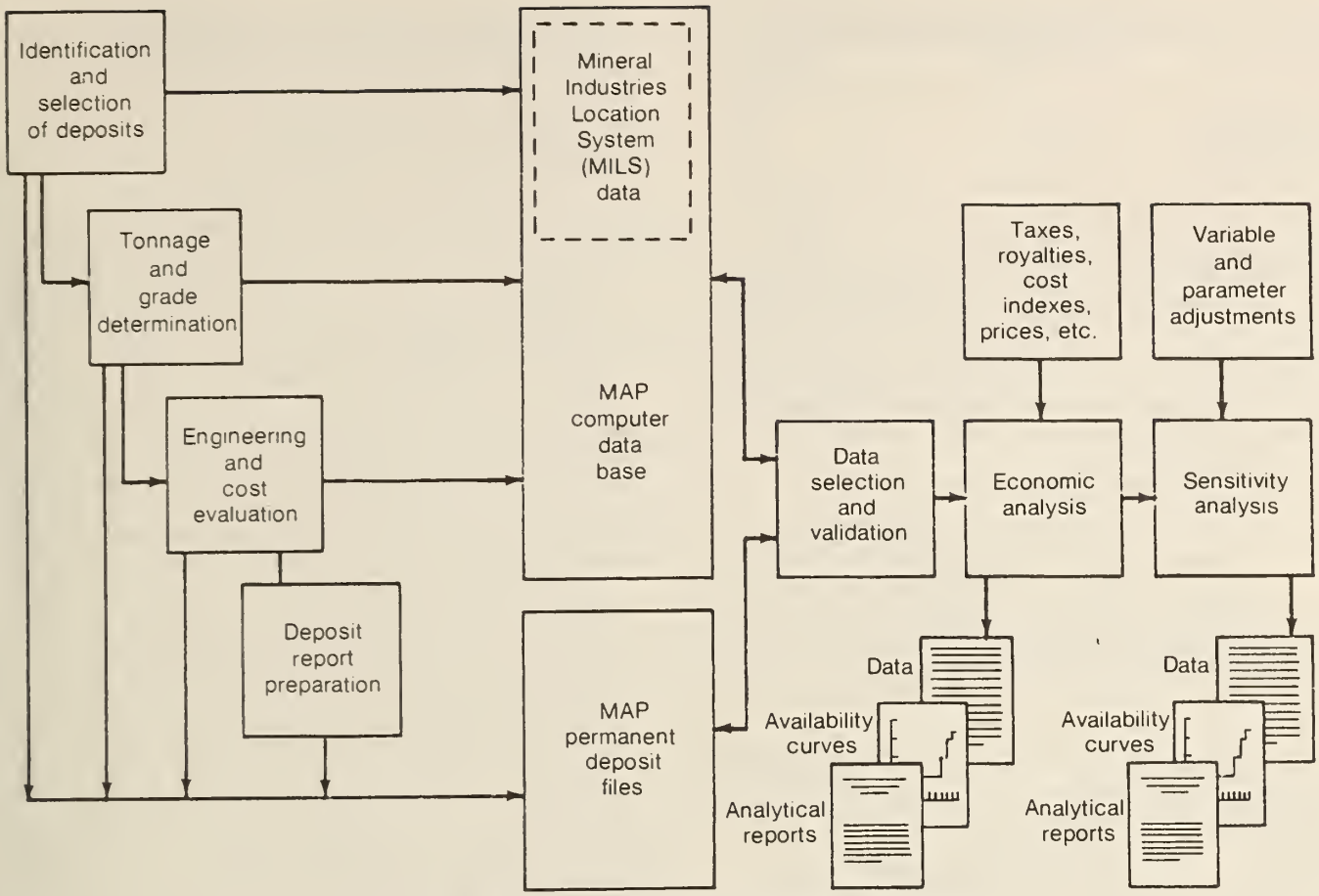

Figure 3.—Minerals Availability program evaluation workflow.

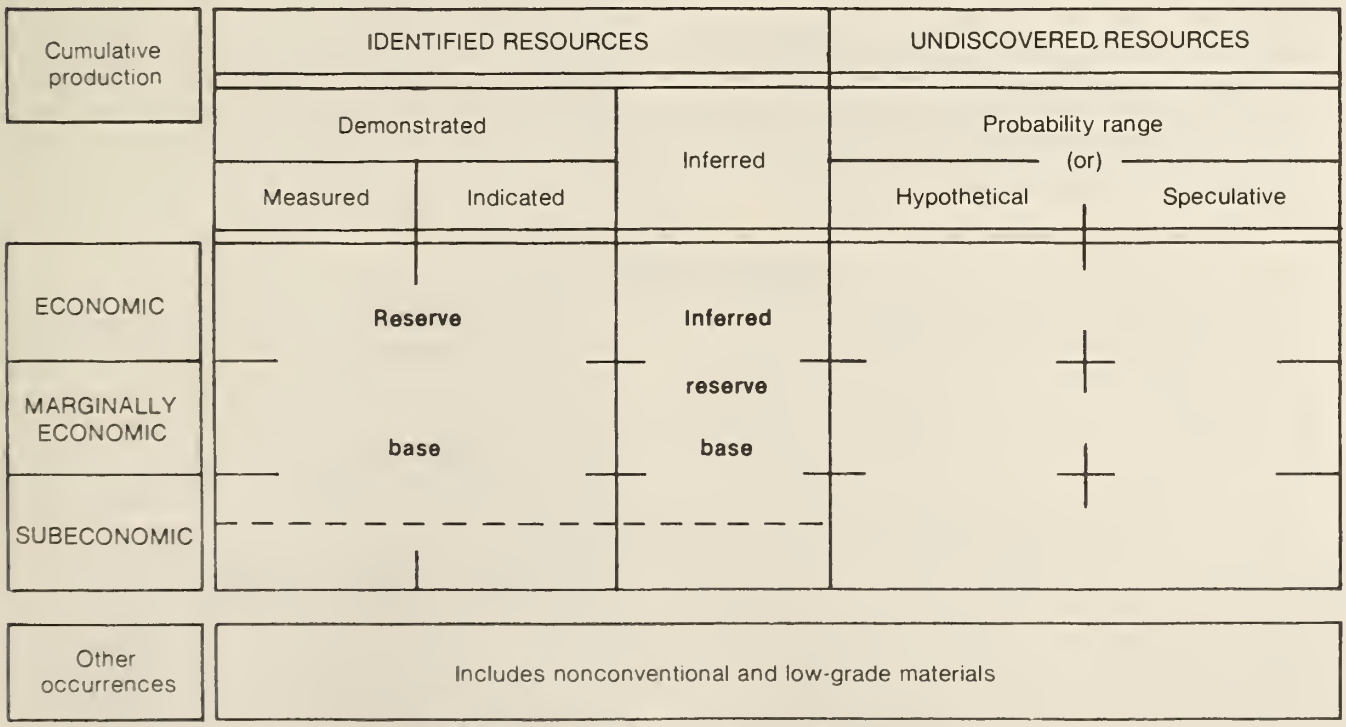

Figure 4.—Mineral resource classification categories.

Table 10.—Byproduct commodity prices, market economy countries, January 1983

	Price, $/lb
Tungsten	$3.24
Tin	5.53
Copper	.78
Molybdenum[1]	3.45

[1]Produced as a byproduct of copper production.

capacity throughout its life (capacities were based on 1983 and/or 1984 company plans or engineering judgments).

2. Competition and demand conditions are assumed such that each operation will be able to sell all its output at its total production cost. This condition implies that the level of molybdenum demand will support the highest cost deposit, or that existing Government subsidies will equal the difference between the market price and the total cost for each submarginal deposit.

3. All byproducts will be sold at the prices shown on table 10.

4. Production costs are for concentrates sold f.o.b. mine; i.e., no transportation or roasting costs are included.

Time lags involved in filing environmental impact statements and receiving necessary permits, financing, etc., were not included in the analysis. Existing laws and regulations, environmental, political, legal, or other constraints may limit production from some of the deposits included in this study.

The byproduct prices used in this study (table 10) were based on 1983 averages. Because the study was conducted using constant 1983 dollars, no escalation of either costs or prices was included.

COST ESTIMATION

When possible, actual company cost data were used. If these data were not available, the required capital and operating costs were estimated by standardized costing techniques.

In some cases costs were estimated from a costing system prepared for the Bureau (*16*). This system is designed to prepare capital and operating cost estimates and is based on an average of the costs for existing mining operations in the United States and Canada. Correct use of this costing system will produce reliable estimates, which historically have fallen within 25 pct of actual costs.

Individually deposit cost data were used to perform an economic analysis for each property. Capital and operating costs for developing and explored deposits were adjusted to average 1983 dollars. Mine and mill capital costs incurred prior to 1983 by producing mines (and some developing and explored deposits) were adjusted to average 1983 using the remaining book value of the investments.

Capital expenditures were calculated for exploration, acquisition, development, and mine and mill plant and equipment. Capital expenditures for mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, infrastructure, and working capital. Infrastructure includes, among other things, the costs of the water system, power system, fire protection, roads, port facilities, construction of necessary rail facilities, and, in remote areas, construction of town and housing facilities. Working capital is a revolving cash fund for such operating expenses as labor, insurance, supplies, and taxes.

Mine and mill operating costs were also calculated for each deposit. The total operating cost is a combination of direct and indirect costs. Direct operating costs include direct and maintenance labor, materials, payroll overhead, and utilities. Indirect operating costs include administrative costs, facilities maintenance and supplies, research, and technical and clerical labor. Other costs not included in operating costs but used in the analysis include deferred expenses, depreciation, insurance, interest payments (if applicable), and taxes.

The Bureau previously developed a Supply Analysis Model (SAM) to perform an economic analysis which presents the result as the primary commodity price (total production cost) needed to provide a stipulated rate of return (*17*). The DCFROR, used in this study, is most commonly defined as the rate of return that makes the present worth of cash flows from an investment equal to the present worth of all after-tax investments (*18*). For this study, a 15-pct DCFROR was considered necessary to cover the opportunity cost of capital plus risk. For some Government-owned operations, a 15-pct DCFROR may not be required for continued production. However, for comparison purposes, each deposit was analyzed at this DCFROR.

For producing mines, analysis was also performed at a 0-pct DCFROR, which is roughly equivalent to a breakeven production cost. In the short run, a mine may continue to produce at molybdenum prices even below this cost in anticipation of improved market conditions.

OPERATING COSTS

The average total capital and operating costs calculated for each of the deposits analyzed include mining, concentrating, and capital recovery, taxes, and profit. These costs often vary greatly, depending on such factors as size of operation, mining method, deposit location, stripping ratio, depth of ore body, grade of molybdenum and byproducts, processing losses, energy and labor costs, and applicable tax structure.

The operating costs presented in this section are based on mining ore and concentrating the ore over the life of the operation. Capital costs for deposits not producing at the time of the study reflect the total investment required to develop a mine, construct all facilities, and begin production. Capital costs for producing mines have less effect because some of the mines have been producing for many years and a large portion of the initial cost has been depreciated.

Weighted average cost data for all primary mines evaluated in the United States and Canada are shown in table 11 on a per-ton-of-ore basis and in table 12 on a per-pound-of-molybdenum basis. To maintain confidentiality, cost data on the two Mexican deposits are withheld. The U.S. producing mines consist of two underground, two surface, and one combined (underground-surface) operation; the Canadian mines includes two surface mines and one combined operation.

The average operating cost on a per-ton-of-ore basis for producing U.S. mines (table 11) is more than twice that of the Canadian mines. This is attributed to the high stripping ratio of U.S. surface mines (3:5:1.0) and the fact that about 50 pct of the U.S. tonnage is from underground operations. In nonproducing mines, the projected cost of U.S. mining is less than half that of the Canadian operations. This is because

Table 11.—Estimated cost of mining and milling operations from primary producers in the United States and Canada, January 1983

	Producers		Nonproducers	
	United States	Canada	United States	Canada
Number of deposits	5	3	7	6
Total annual ore capacity, 10³mt	47,781	14,987	67,730	23,153
Av feed grade, pct Mo	0.1696	0.092	0.100	0.073
Av operating cost, $/mt ore:				
Mine	7.03	$2.79	$2.87	$6.78
Mill	3.14	$2.83	$3.40	$2.78

six of the seven projected U.S. mines would use surface methods, whereas four of the six projected Canadian mines would be underground. Comparing U.S. mines, the producers show a much higher mining cost than the nonproducers. This is due to the higher stripping ratio experienced by producers and the higher percentage of ore produced by underground methods.

The per-ton cost for beneficiation reflects small differences between U.S. and Canadian operations. The five producing U.S. mines averaged $3.14/mt ore, while the three Canadian mines averaged $2.83/mt. The added cost of byproduct recovery made the U.S. operations slightly higher than Canadian mines, which produce no byproducts.

When costs are converted from dollars per metric ton of ore to cents per pound of molybdenum contained in concentrate, the average operating cost for producing U.S. mines is $3.15/lb, $2.16/lb for mining and $0.99/lb for milling. Operating costs for Canadian mines average $3.38/lb, $1.54/lb for mining and $1.84/lb for milling. On a cost per metric ton of ore basis, mine operating costs for producing U.S. mines are 2.5 times greater than for Canadian producing mines. However, owing to the much higher ore grade of the mines, costs on a per pound basis are only 1.4 times higher. For milling, U.S. mines have a cost advantage over Canadian mines owing to a higher ore grade (0.1696 pct compare with 0.092 pct) and economies of scale of the larger U.S. milling operations. The annual capacity of the five U.S. milling operations in 1983 averaged 9.6 million mt ore, while the three Canadian mines averaged only 5.0 million mt. The difference in mill operating costs between U.S. producing and nonproducing mines is due primarily to the much lower grade (0.09 pct compared with 0.1696 pct) of the nonproducing deposits.

Taxes for producing mines in the United States and Canada are nearly equal, averaging $0.10/lb in the United States and $0.11/lb in Canada. Taxes are greater for nonproducers because, in most cases, the revenues required to cover the higher production costs (incl ding recovery of capital) are greater.

Table 12.—Estimated mine and mill operating costs[1] for primary molybdenum procuers in the United States and Canada, January 1983

(Dollars per pounds molybdenum contained in concentrate)

Cost	Producers		Nonproducers	
	United States[1]	Canada[2]	United States[1]	Canada[2]
Operating cost:				
Mine	$2.16	$1.54	$1.43	$4.30
Mill	.99	1.84	2.52	2.27
Total	3.15	3.38	3.95	6.57
Taxes	.10	.11	.17	.12
Capital recovery	.52	.60	.96	1.77
Byproduct credit	(−.30)	(−.00)	(−.25)	(−.09)
Breakeven cost[3]	3.47	4.09	4.83	8.37
Total cost[3]	4.28	5.62	9.03	27.26

[1]Costs based on total annual capacity for molybdenum in concentrate as shown below:

	Number of mines	Mo in conc, 10⁶ lb/yr
Producers:		
United States	5	161
Canada	3	25
Nonproducers:		
United States	7	133
Canada	6	33

[2]Mine and mill cost, plus taxes and capital recovery, less byproduct credits (as shown).
[3]Breakeven cost plus profit at a 15-pct DCFROR.

The capital recovery cost reflects the complete recovery of all capital investments allocated on a per-pound-of-production basis over the life of the mine. This cost averaged $0.52/lb for U.S. producers and $0.60/lb for Canadian. Costs for nonproducing deposits are much higher (particularly in Canada), since none of the capital cost has been depreciated, as it has for producing mines.

Byproduct credits (WO_3, Sn, and Cu) provide an added benefit to U.S. producers, averaging $0.30/lb Mo. Canadian producing mines, on the other hand, produce no byproducts.

Producing U.S. mines average $3.47/lb, while Canadian producers average $0.62/lb higher at $4.09/lb. Total costs of nonproducing U.S. deposits are more than double those of producing mines; in Canada the nonproducer total cost is nearly triple the producer total cost.

Breakeven cost reflects the cost of production at which the mines would break even and cover all production costs after credit for byproducts. Total cost includes net cost plus profit at 15-pct DCFROR. Total costs are much higher for nonproducers because greater revenues are required to provide profit on the larger capital investment.

CAPITAL COSTS

To estimate the capital costs for explored and developing properties, exploration, acquistion, development, mine and mill plant and equipment, and infrastructure costs were calculated. Capital costs beyond beneficiation, such as for roasting, were not included in the analyses. A total of 14 properties, 9 surface and 5 underground, were evaluated for this section. Capital costs according to mine type and ore capacity are shown in table 13. All costs were adjusted to January 1983 dollars. Actual cost for individual deposits may vary greatly depending on required infrastructure, exploration and development works, size of operation, characteristic of the orebody, and complexity of the ore.

The average capital cost of nine surface mining operations was estimated at $269 million, or $18.92 per pound of annual molybdenum capacity. This compares with an average cost of five underground operations of $286 million, representing $19.60 per pound of annual capacity.

In both surface and underground operations, cost per pound of annual capacity was lower for the larger mines, representing some economies of scale. However, most of the

Table 13.—Estimated capital costs for developing and explored molybdenum deposits, market economy countries, January 1983
(Thousand dollars)

	Number of mines	Av capacity, mt/d ore	Acquisition, exploration, development	Mine	Mill	Infra-structure	Total cost	Capital cost, per lb annual capacity
Surface:								
<10,000	2	8,141	$23,000	$30,830	$41,400	$44,030	$139,260	$35.80
10,001 to 20,000	4	17,221	17,320	33,300	97,560	25,990	174,170	17.57
>20,000	3	43,840	54,150	103,670	292,960	42,250	493,030	16.31
Total or average	9	23,067	$31,490	$55,933	$143,973	$37,423	$268,819	$18.92
Underground:								
<10,000	3	5,066	$19,230	$19,850	$38,950	$38,150	$116,180	$26.39
>10,000	2	25,200	195,100	60,170	103,610	97,790	456,670	18.23
Total or average	5	15,133	$107,165	$40,010	$71,280	$67,970	$286,425	$19.60

capital cost differential was due to higher proportional costs for exploration and development and infrastructure in the smaller mines; for example, infrastructure costs for the smallest group (less than 10,000 mt/d ore) of surface operations were actually higher than total such costs for the largest (greater than 20,000 mt/d ore) surface mines.

MOLYBDENUM AVAILABILITY

EVALUATION METHODOLOGY

After cost and resource data were determined for each deposit, total and annual resource availability curves were constructed to illustrate molybdenum availability. These curves are discontinuous functions relating the total cost (as defined in the "Assumptions" section) for a deposit to its level of production. The total or annual quantity of molybdenum from each deposit was accumulated from lowest to highest total cost to show molybdenum availability.

A total resource availability curve is not an ordinary supply curve because it does not consider the time parameter and is not the industry's marginal cost curved. Rather, a total resource availability curve is an aggregate of the total production potential at a stipulated cost that covers full production costs.

For the engineering analysis, it was necessary to determine a development schedule for each property. For producing mines, expansions considered to have a high probability of occurring were included. For nonproducing deposits, the time required for development depends upon the exploration, extent of preproduction development, plant construction, and infrastructure requirements. Annual resource availability curves are disaggregations of total resource curves to an annual production basis. Compared with total availability curves, annual availability curves more closely resemble true supply curves since they show annual production; but they also indicate average total cost of production rather than marginal cost.

Separate annual availability curves were constructed for producing mines and nonproducing (developing and explored) deposits. Annual curves for producing mines show the molybdenum capacity of existing mines and planned expansions when known. Annual curves for most nonproducing deposits are not related to any given year, since the startup year is uncertain. They do, however, show required lead times before production can begin and indicate potential annual production capabilities.

TOTAL AVAILABILITY

At the demonstrated resource level potential recoverable molybdenum from primary mines was estimated at 9.6 billion lb, with an additional 6.6 billion lb available from primary copper mines.

With 15-pct DCFROR on invested capital, a total of 8.9 billion lb would be available from the primary deposits at production costs ranging from $3.20/lb to $14/lb Mo (figure 5 and table 14). The remaining 712,000 lb would have a production cost exceeding $14/lb. In January 1983, dealers were selling the metal for $2.47/lb, a price well below the production cost of primary producers. Analyses indicated that virtually the only supply source that could provide molybdenum at this price would be byproduct producers, especially from the foreign copper operations.

At a price of $10/lb, approximately equivalent to the 1980 selling price, the available resource would be 7.9 billion lb. However, at $4.50/lb, the 1982 selling price, the available resource drops to 2.5 billion lb. When dealers were selling the metal at $2.47/lb, analyses indicated that only one primary mine could cover production costs (DCFROR, breakeven cost) (fig. 6). Costs reflected in figure 6 include capital recovery; hence these costs should not be interpreted as cash cost equivalents.

Producing mines account for 43 pct of the tonnage potentially recoverable from primary properties, while deposits under development account for 22 pct; explored deposits, having no specific plans for development, account for the remaining 35 pct.

The weighted-average cost of production for producing mines (including a 15-pct DCFROR) is estimated to be $4.46/lb Mo; nearly 2.5 billion lb is available at a molybdenum price of $4/lb. At $6/lb, the available molybdenum from pro-

Table 14.—Molybdenum potentially available from primary producing, developing, and explored deposits in market economy countries at selected 1983 prices, at a 15-pct DCFROR
(Million pounds of contained molybdenum)

Total cost $/lb	Producing mines	Developing and explored deposits	Total[1]
Under $4.00	2,463	0	2,463
$ 4.01 to $ 6.00	1,002	0	1,002
$ 6.01 to $ 8.00	630	610	1,240
$ 8.01 to $10.00	0	3,200	3,200
$10.01 to $14.00	0	1,009	1,009
Above $14.00	0	712	712
Total[1]	4,096	5,531	9,626

[1]Totals may not add owing to independent rounding.

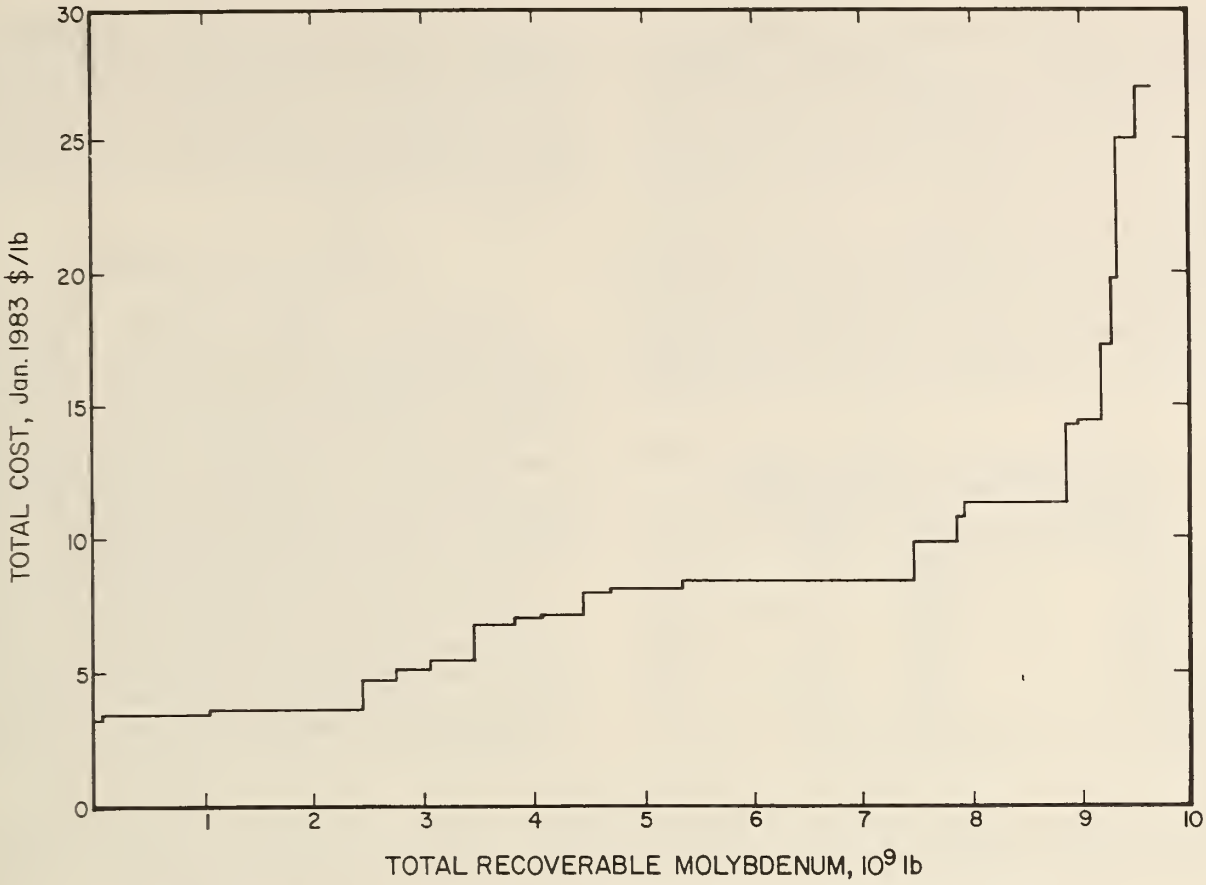

Figure 5. —Total molybdenum available from primary deposits, market economy countries.

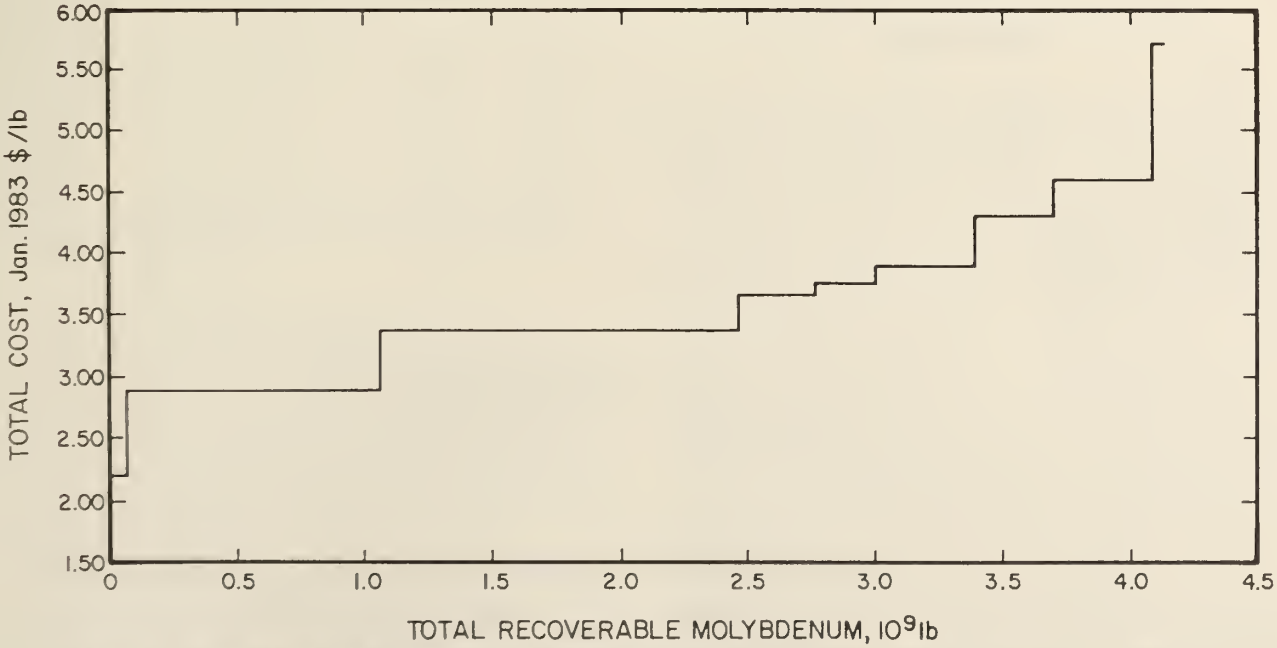

Figure 6. —Total molybdenum available from producing mines at a 0-pct DCFROR, market economy countries.

ducing mines increases by 1.0 billion lb. At these prices no tonnage is available from the nonproducers. However, at $8/lb, an additional 1.2 billion lb would be available, nearly half of which would be from deposits not currently producing. At prices exceeding $8/lb, an additional resource of 4.9 billion lb is potentially available, entirely from nonproducing deposits.

The total potential availability of primary molybdenum from properties within Canada and the United States constitutes 97 pct of the total resource. Shown in figure 7 are curves illustrating the molybdenum availability of each country. These data are grouped in various price categories in table 15. At a price under $4/lb and a 15-pct DCFROR, the United States has a potential available resource of 2.4 billion lb, enough to supply current domestic requirements for at least 40 yr. A price of $6/lb would bring an additional resource of 697 million lb from U.S. deposits for a total of 3.1 billion lb. At the same price, Canada could produce a total of 305 million lb. At a price exceeding $8/lb, U.S. deposits could produce an additional 4.2 million lb, while Canada could mine an additional 721 million lb.

Table 15.—Molybdenum potentially available[1] within the United States and Canada, at a 15-pct DCFROR

(Million pounds or recovered molybdenum)

Total cost, $/lb	United States	Canada	Total
Under $4.00	2,396	0	2,396
$ 4.01 to $ 6.00	697	305	1,002
$ 6.01 to $ 8.00	757	241	998
$ 8.01 to $10.00	3,200	0	3,200
$10.01 to $14.00	952	57	1,009
Above $14.00	48	664	712
Total[1]	8,050	1,267	9,317

[1]Includes both producers and nonproducers.

ANNUAL AVAILABILITY

The estimated molybdenum production capacities for the deposits analyzed are shown in table 16. At full capacity levels, a total production of 337 million lb is available from the market economy countries—179 million lb from the producing mines and 158 million lb from nonproducers. All production capacity from operating mines would be available at a cost of $8/lb or less, while explored deposits could only contribute 25 million lb at that price. Additional production capacities would be available at costs ranging up to $14/lb, all from developing and explored deposits.

Figure 8 shows potential annual molybdenum production at various cost ranges for producing mines and nonproducing deposits. The large increase in production from 1983 to 1984 for producing mines occurs because many mines were shut down in 1983 and were assumed to be reopened in 1984. The production from 1984 to 2000 for these mines represents molybdenum output potential at full-capacity levels of pro-

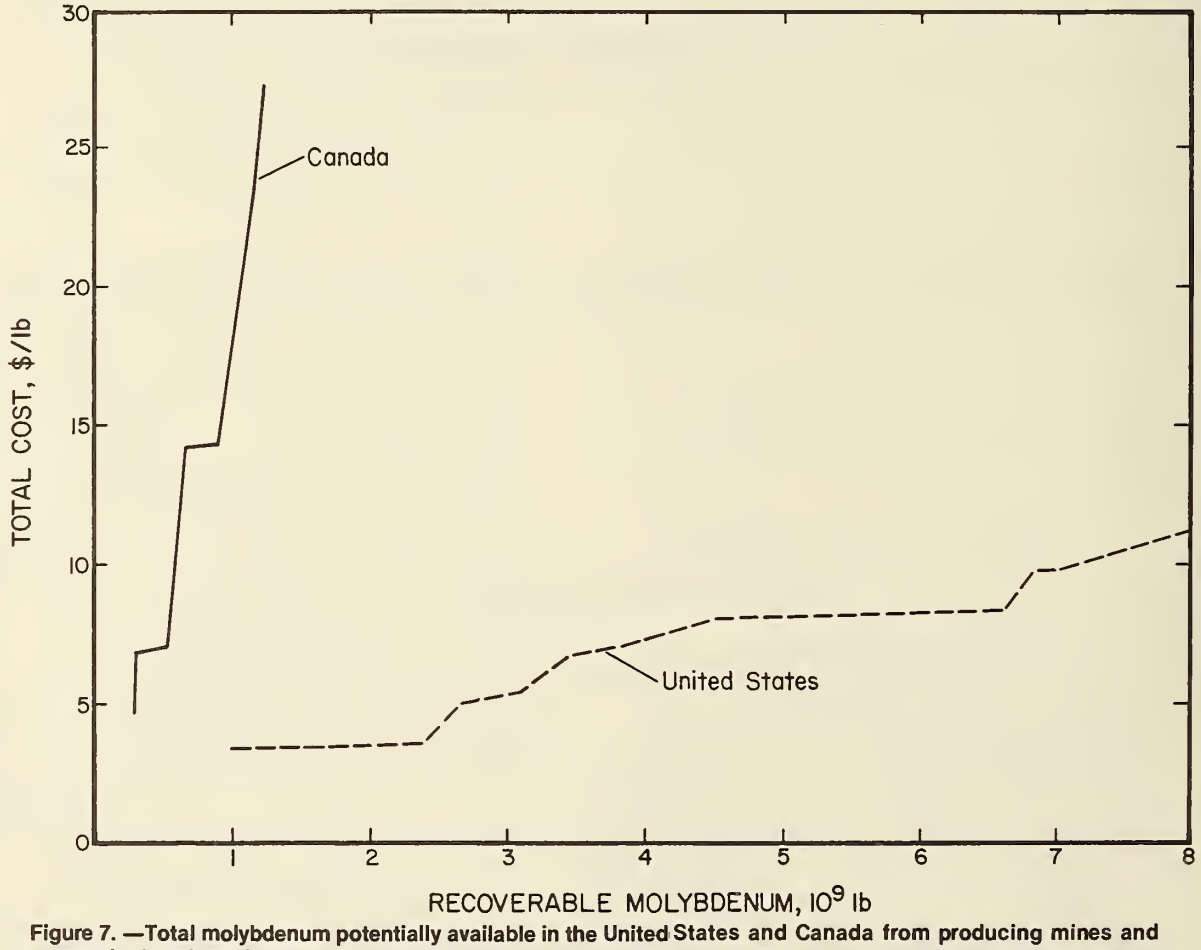

Figure 7. —Total molybdenum potentially available in the United States and Canada from producing mines and nonproducing deposits.

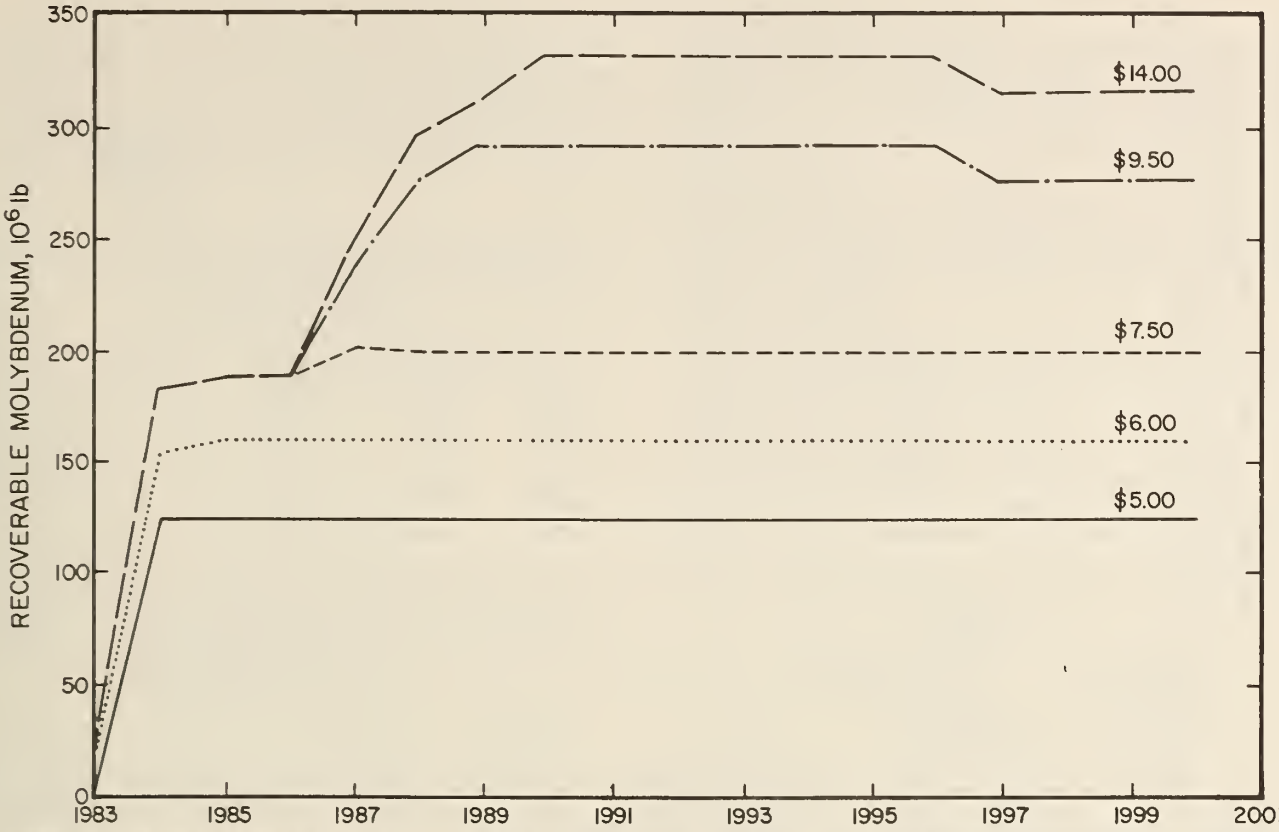

Figure 8.—Potential annual production of molybdenum from producing mines and nonproducing deposits at various cost ranges, market economy countries.

Table 16.—Potential 1983 molybdenum production capacities from primary molybdenum mines and deposits in market economy countries, at a 15-pct DCFROR

(Million pounds of contained molybdenum)

Total cost $/lb	Producing mines	Developing and explored deposits	Total[1]
Under $3.50	44	0	44
$ 3.51 to $ 4.75	74	0	74
$ 4.76 to $ 6.00	34	0	34
$ 6.01 to $ 8.00	27	25	52
$ 8.01 to $ 9.00	0	62	62
$ 9.01 to $12.00	0	40	40
$12.01 to $14.00	0	0	0
Above $14.00	0	31	31
Total	179	158	337

[1]Installed capacities for producing mines and projected capacities for developing and explored deposits.

duction. The fact that the curves for producing mines do not decrease indicates that these mines have sufficient reserves to produce at full capacity until sometime after the year 2000. At a cost of $3.50/lb with 15-pct DCFROR, an annual production of 44 million lb would be economically available from producing mines. At $4.75/lb, production would increase to a total of 118 million lb/yr; while at $8, all producing mines could economically operate.

Because startup dates for developing and explored deposits were not known, construction of annual availability curves for them were based on the assumption that preproduction would begin in year "N" (fig. 9). These curves indicate that several years would be required from the year development begins before any production could occur. Although an additional 133 million lb/yr Mo could be produced from these deposits, a price exceeding $8/lb would be required. Therefore, for most of these deposits, production in the near future appears unlikely.

BYPRODUCT MOLYBDENUM TOTAL AVAILABILITY

A significant portion of molybdenum production is as a byproduct of copper; production from this source has been increasing in recent years. A total of 65 copper deposits were analyzed for molybdenum production, 34 producers and 31 nonproducers. A total of 14 domestic copper operations were evaluated as producers, some of which are temporarily closed.

As shown in figure 10, the total byproduct availability from all mines evaluated amounts to approximately 6.6 billion lb Mo at a price up to $3.80/lb Cu, with producers accounting for over 65 pct of the total. As shown in table 17, a total of 1,435 million lb Mo could be economically mined at a copper price under $0.50/lb, with an additional 1,986 million lb available at prices up to $0.75/lb. At higher copper prices (exceeding $2.25/lb) a total of 6,608 million lb Mo is potentially available, two-thirds of which would be from producing mines.

Annual availability from all mines evaluated amounts to an annual capacity of 47.1 million lb Mo. Table 18 shows the U.S. molybdenum capacity from operating or temporarily shut down copper mines for 1983. At a copper price of $0.75/lb the domestic molybdenum producers can supply 22.3 million lb Mo from two copper mines. An additional capacity of 6.1 million lb can be generated at a copper price of $1.00/lb. The remaining capacity requires a copper price greater than

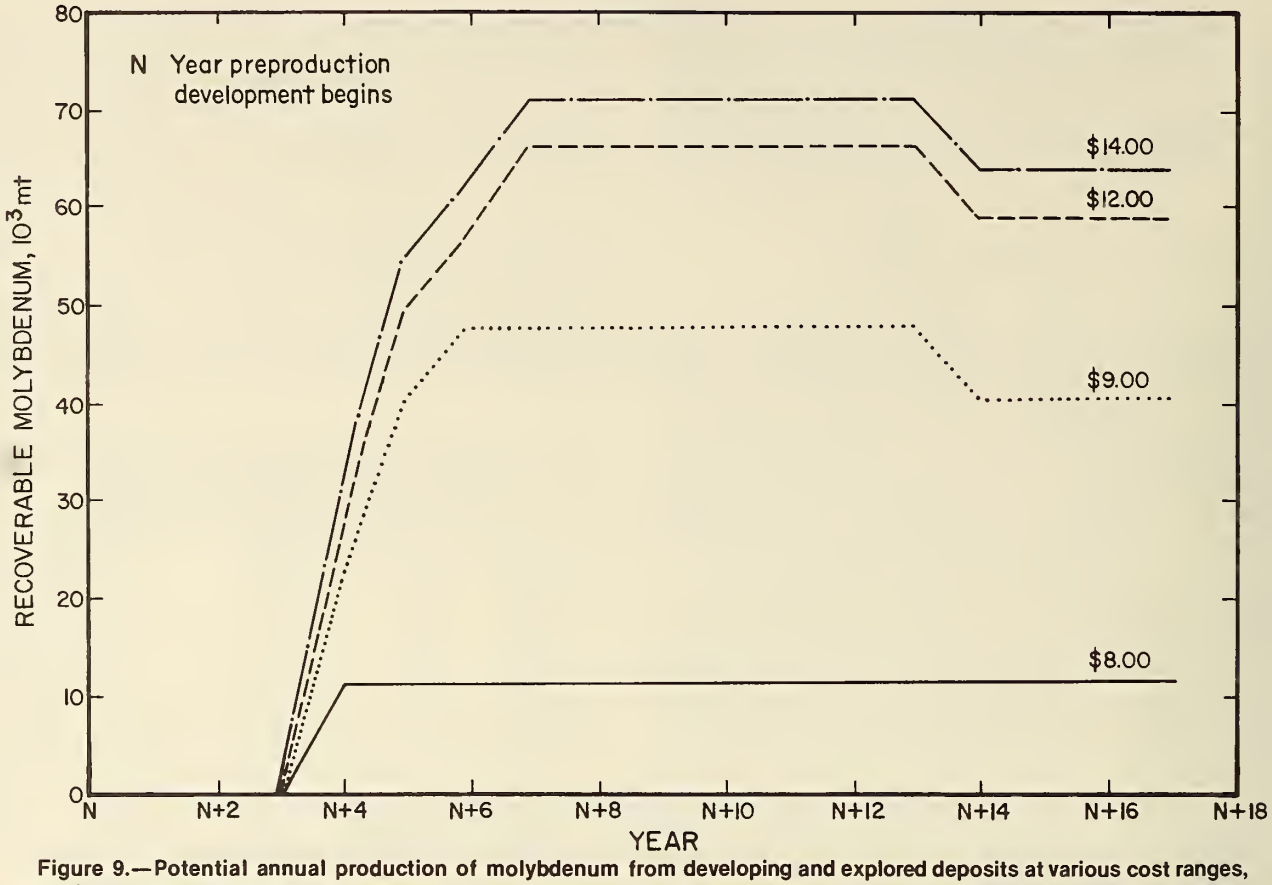

Figure 9.—Potential annual production of molybdenum from developing and explored deposits at various cost ranges, market economy countries.

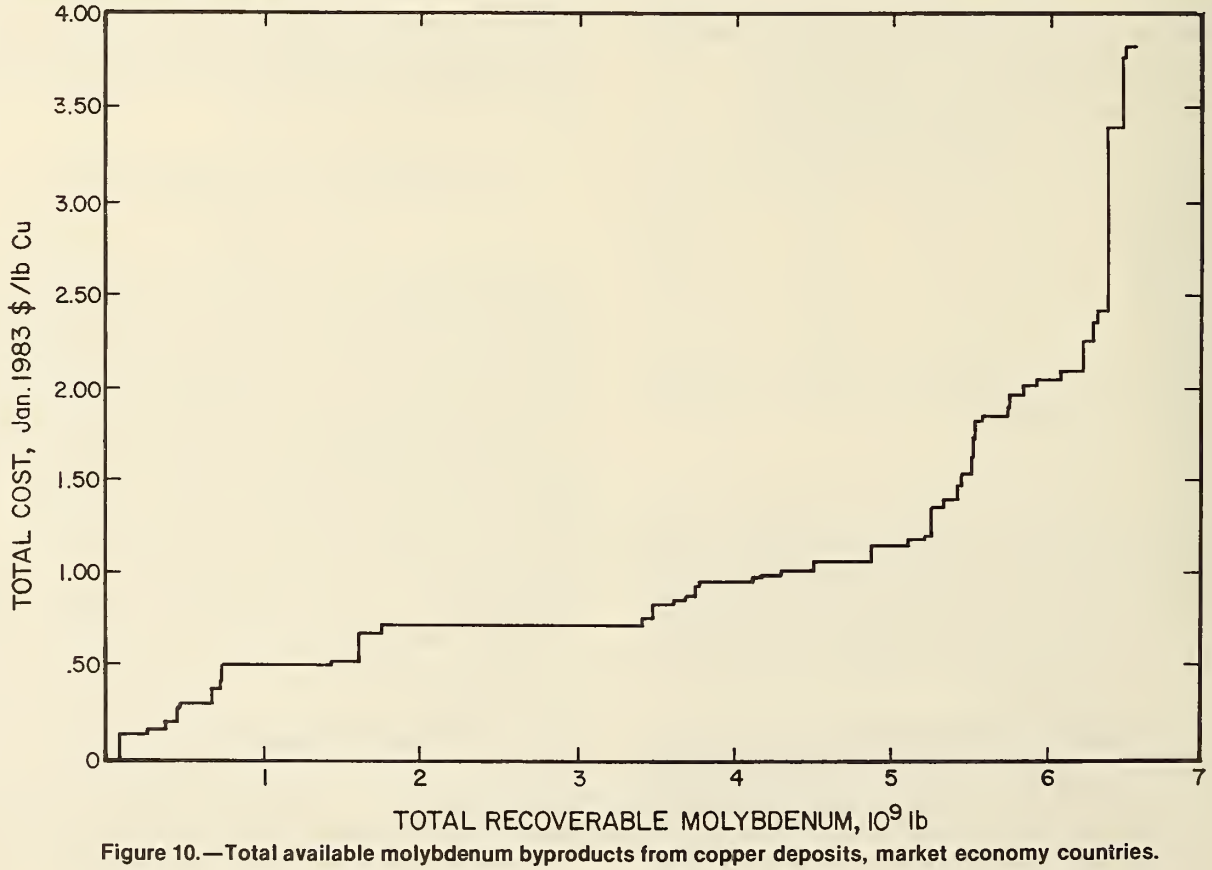

Figure 10.—Total available molybdenum byproducts from copper deposits, market economy countries.

$1.00/lb to be economically extractable. At copper prices above $1.00/lb molybdenum production is questionable since many of these mines are now shut down. It is likely that many of these mines will remain closed owing to the availability of cheaper byproduct molybdenum from copper operations in foreign countries.

Table 17.—Total molydenum byproduct potentially available in market economy countries at selected copper production costs, at a 15-pct DCFROR

(Million pounds of molybdenum)

Copper price, $/lb	Producing mines	Developing and explored deposits	Total
Under $0.50	1,005	430	1,435
$0.51 to $0.75	1,810	176	1,986
$0.76 to $1.00	760	136	896
$1.01 to $1.50	706	443	1,149
$1.51 to $2.25	137	715	852
Above $2.25	0	290	290
Total	4,418	2,190	6,608

Table 18.—Annual U.S. byproduct molybdenum capacity and total demonstrated resources of recoverable molydenum from evaluated U.S. copper operations at selected copper prices, at a 15-pct DCFROR

(Million pounds of molybdenum)

Copper price, $/lb	Annual capacity, 1983	Total resources
Under $0.75	22.3	294.4
$0.76 to $1.00	6.1	131.7
$1.01 to $1.50	16.2	495.9
Above $1.50	2.5	7.6
Total	47.1	929.6

Estimated annual production capacities for byproduct molybdenum from primary copper deposits are shown in table 19. Capacities, as shown, were estimated at full designed capacity for the years 1983 and 1991. A total production capacity of 109 million lb was estimated for 1983 from producing mines, with the United States contributing 47 million lb. As shown, there are planned capacity increases in producing mines of over 25 pct by 1991. In addition, deposits not now producing have the potential to add nearly 70 million lb/Mo, although for most deposits, much higher copper prices would be required.

Since copper price influences molybdenum production, potential annual molybdenum capacity was analyzed on the basis of copper price (fig. 11). As shown, at a copper price of $0.50/lb, annual production capacity in 1983 was estimated at 25 million lb from seven properties. As these mines expand molybdenum production capabilities, capacity could approach 50 million lb/yr. At a copper price of $1/lb, production capacity for 1983 increases to 64.0 million lb. At the same

Table 19.—Molybdenum byproduct potential annual production for 1983 and 1991 from market economy countries, at a 15-pct DCFROR

(Million pounds of contained molybdenum)

Copper price $/lb	1983 capacity: Producing mines	1991 capacity		
		Producing mines	Nonproducing deposits	Total
Under $0.75	51.7	74.2	20.4	94.6
$0.75 to $1.00	12.4	26.0	0.0	26.0
$1.00 to $1.50	34.6	30.4	21.6	52.0
$1.50 to $2.25	10.5	8.7	27.6	36.3
Total	109.2	139.3	69.6	208.9

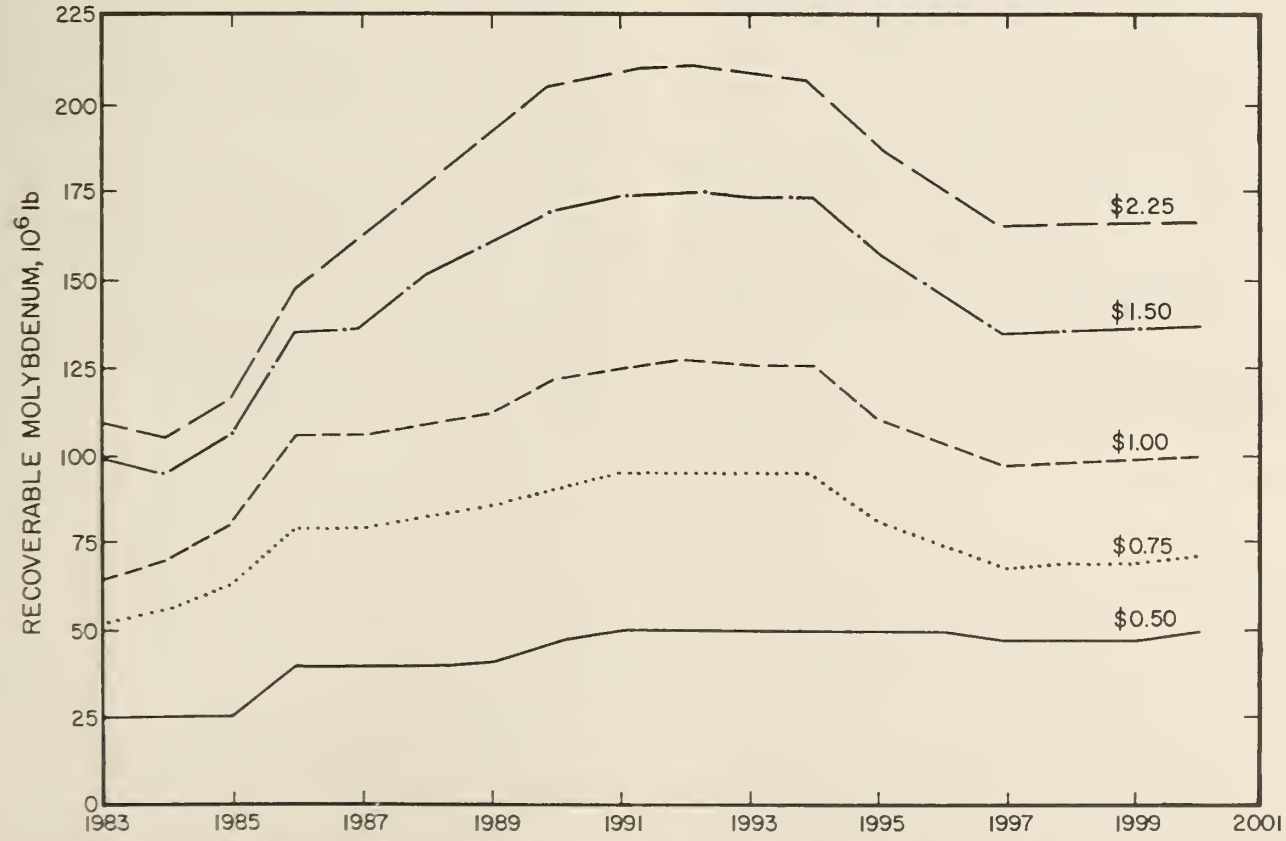

Figure 11.—Potential annual capacity of molybdenum byproducts at selected copper prices, market economy countries.

price, 124.8 million lb/yr capacity would be available from 28 properties in 1991, 80 pct of which would be from mines currently producing. As shown, molybdenum as a byproduct of copper production could exceed 200 million lb/yr. However, prices well above $1.00/lb would be required.

Table 20 shows the 1983 estimated installed molybdenum capacity on a country basis for producing mines. Among primary producers, the United States accounts for 153 million lb/yr or 85 pct of the total capacity, while Canada and Mexico hold 13 pct and 2 pct, respectively. In byproduct production, the United States has the capacity to produce 47 million lb/yr, 34 pct of the total. Chile has a production capacity of 45 million lb/yr, with Canada following at 21 million lb/yr. The remaining capacity is divided between four countries: Mexico, Peru, Iran, and the Philippines.

As shown in the table, the installed capacity far exceeds the MEC production, which has averaged 178 million lb/yr over the last 10 yr. In addition, private inventories estimated at 200 million lb in 1983 have contributed to the oversupply of molybdenum (*19*). As a result, there is little likelihood for explored primary deposits to be developed in the foreseeable future. It is more likely that planned expansions by byproduct producers will continue to affect primary production and, as a result of continued overcapacity conditions, molybdenum price will tend to remain low.

Table 20.—Estimated total 1983 molybdenum capacity from primary and byproduct producers in market economy countries

(Million pounds of molybdenum)

Country	Primary	Byproduct	Total
United States	153	47	200
Canada	23	21	44
Mexico	3	10	13
Chile	0	45	45
Peru	0	9	9
Iran	0	4	4
Philippines	0	1	1
Total	179	137	316

CONCLUSIONS

The United States has about 8.1 billion lb Mo (recoverable) from primary deposits and 1.2 billion lb as a byproduct of copper production. This constitutes 84 pct of all recoverable primary resources located in the MEC'S, and 17 pct of the recoverable byproduct resource. The current U.S. production capacity is estimated at 153 million lb from primary producers and 47 million lb from byproduct producers, a total of 200 million lb/yr. This capacity is well above the domestic consumption requirement, which has a 10-yr average of about 57 million lb/yr. Disregarding economics, available U.S. resources could supply current domestic demand at this level for at least 160 yr. Assuming production at the average rate over the last 10 yr (about 114 million lb/yr), U.S. resources could last for over 80 yr.

Applying profitability at a 15-pct DCFROR on invested capital and a price of $4/lb Mo, 2.5 billion lb of Mo could be recovered from MEC primary mines. If the molybdenum price were to increase to $6/lb, an additional 1 billion lb would be available. There are also large resources (5.5 billion lb Mo) potentially available from primary deposits that are not now producing; however, prices exceeding $14/lb would be required.

With such a large resource base located within the territorial boundaries of the United States, molybdenum availability is well assured regardless of international trade disruption. However, most of these resources can only be produced at prices higher than those prevailing today (1983).

As major international molybdenum suppliers, primary U.S. producers are threatened by foreign byproduct producers. As new foreign byproduct production capacity comes on-stream, large quantities of molybdenum will be available to the international market. In effect this could dislocate some primary suppliers, which require higher molybdenum prices in order to profitably operate. In recent years, primary mines have cut back production, and in 1983 production at all primary U.S. mines was halted. Unless market conditions significantly improve, the outlook for these primary producers is bleak.

Byproduct production is less sensitive to molybdenum price changes since the operation is more dependent on copper price. In addition, many of the byproduct properties are located in countries where employment and the need for foreign currency are the primary concerns rather than profitability. Even under continued poor economic conditions, molybdenum production from these sources will continue to be available. Furthermore, the production from these countries is expected to increase, owing to planned copper mine expansions and new mine developments.

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APPENDIX.—DEPOSIT DESCRIPTIONS FOR PRIMARY MOLYBDENUM

UNITED STATES

Alaska

Quartz Hill

The Quartz Hill deposit is located on a knoll bounded by the Wilson Arm-Smeaton Bay Fjords on the north and the Boca de Quadra fjord on the south. It lies within a transitional zone between the Wrangell-Revillagigedo Belt metamorphic complex to the west and the massive Coast Range Batholith rocks to the east. The deposit is situated approximately at N55° 24'05" latitude and W130° 29'00" longitude.

Metavolcanic and metasedimentary rocks of Mesozoic and/or Paleozoic age are the oldest rocks exposed in the area. The Coast Range rocks vary in composition from diorite, quartz diorite, and granodiorite to quartz monzonite. These quartz-and sodium-rich monzonites are the sources and primary hosts for the molybdenum mineralization. The main mass of the Quartz Hill stock is a textured porphyritic quartz monzonite (*20*).[1]

U.S. Borax and Chemical Co. began exploration work on the Coast Range intrusive complex in 1971. Several years of both bedrock and geochemical sampling indicated the presence of molybdenum in the area and resulted in the discovery of the Quartz Hill deposit. Initial core drilling made in 1974-75 confirmed Quartz Hill as a molybdenum deposit. By the end of 1978, a total of 280 shallow and deep drill holes delineated at least 635 million mt of ore at 0.09 pct Mo. As of 1981, 70,492 m of core drilling were completed, delineating a total of 1.36 billion mt ore at an average grade of 0.081 pct Mo.

The deposit, as planned, will be mined by open-pit methods. Mine development will consist of removing 11.8 million mt ore and waste rock during the first year and processing approximately 9.9 million mt ore. The pit will have an ultimate length of 3.38 km, a width of 2.09 km, and an average depth of 488 m. Based upon a mining rate of 54,420 mt/d, the mine could produce 40 million lb of contained molybdenum in concentrate per year for about 70 yr (*21*).

Colorado

Colorado accounts for about 22 pct of all known domestic resources, in terms of recoverable metal. The three major ore bodies are Climax, Henderson, and Mount Emmons. At present, these deposits contain about 3.1 billion lb of recoverable molybdenum, with Climax and Henderson having a combined annual capacity estimated at more than 100 million lb of Mo.

All three deposits are located in the same geologic province, the Colorado mineral belt. Climax and Henderson are located close to major Tertiary faults, the Mosquito fault and the Berthoud Pass fault, respectively (*22*). The ores are associated with composite intrusives of nearly identical age and composition. Multiple intrusions and mineralizations are characteristics of the deposits.

[1] Italicized numbers in parentheses refer to items in the list of references preceding the appendix

Climax

The Climax molybdenum mine is in the Robinson mining district, on the boundary between Lake and Summit Counties, at about N39° 22'09" latitude and W106° 10'17" longitude. The deposit was first discovered in 1879 and all early work was directed towards gold, but after several years of fruitless exploration, the owner sold the property. The new owner dug an exploratory tunnel into the Bartlett Mountain hoping to intercept gold veins, until it was determined the mountain contained the element molybdenum.

The Climax ore body was formed by a massive Tertiary stockwork in Precambrian granite and schist. The well-mineralized, quartz-porphyry stockwork is a component of the intrusive complex known as the Climax Group (*23*).

The ore body has an elliptical shape with a radius of 550 m at the outer section and 340 m at the central barren core. The ore deposit appears arcuate with a vertical height of about 425 m in its greatest dimensions. The final depth has not yet been reached.

Molybdenite occurs in three distinct, but overlapping ore bodies. The molybdenite is finely crystalline and intimately intergrown in, or enclosed by, quartz. The deposit also contains tungsten (as huebnerite) and tin (as cassiterite) in recoverable quantities. Other minor minerals are monazite, galena, and sphalerite.

In 1916 during a tungsten shortage, the American Metal Co. began to explore and develop the property; as substitute for tungsten, molybdenum demand improved. The Climax Molybdenum Co. was formed to operate the property.

A 227 mt/d mill began production in February 1918, but was forced to close in March 1919 owing to declining demand. The mill remained closed until August 1924 when increasing demand for the metal led to its reopening at a capacity of 363 mt/d (*24*). Since then, production has increased to the current combined capacity of 54,420 mt/d from two mines, an underground block-caving operation and an open-pit operation developed in 1973.

Though it is one deposit, reserves are classed in two separate categories, underground and surface. The full extent of mineralization at Climax is not fully defined. As of January 1983, the underground operation had an in situ reserve of 244.0 million mt ore, and the open-pit operation had reserves of 130.6 mt (*25*).

Henderson

The Henderson Mine lies in the Urad mining district in Clear Creek County. The deposit has location coordinates of N39° 46'09" and W105° 50'29".

The Henderson ore body is near the western edge of the Colorado mineral belt. The molybdenite stockwork ore body is associated with a rhyolitic subvolcanic center commonly referred to as the Red Mountain complex. The complex consists of a number of chemically and mineralogically related intrusive rocks. The primary units of concern are the Urad Porphyry, Primos Porphyry, and the Henderson Granite.

Molybdenum mineralization occurs as veinlets, as coatings on joints, and as disseminations. Veinlet molybdenite, typically 2 to 25 mm thick, accounts for the majority of the ore. It is fine grained and mixed with gangue mineral, primarily quartz, pyrite, fluorite, sericite, and

potassium feldspar. The lower part of the ore body, especially the Henderson Granite, contains a different type of molybdenite veinlets which are generally larger and contain different gangue mineral associations. The veinlets imply replacements rather than open space filling (*22*).

In plan, the ore body is elliptical in shape, about 915 m in the long axis and 700 m in the short. The thickness varies from 120 to 240 m, but depths to the south and east are still unknown.

The Red Mountain area was first prospected in the late 1800's because of the red rocks produced from iron staining. With the absence of gold and silver, little activity occurred until 1914, when the Primos Chemical Co. acquired the property and began developing the Urad mine for molybdenum. Production was sporadic until Climax Molybdenum Co. acquired the property in 1963 (*26*).

The Henderson ore body was discovered from an exploratory program trying to find extensions of the Urad ore body. This led to the discovery of the Henderson ore body on the other side of Red Mountain, but considerably deeper than the Urad ore body (*27*).

The mine employs the panel-caving system, with a capacity of 27,210 mt/d Mo ore. The mining system makes full use of raise boring machines, LHD'S and rubber-tired drill jumbos. Henderson ore reserves have been increasing since discovery. The recoverable reserves as of January 1983 are 223 mt ore at an average grade of 0.251 pct Mo. Based on these reserves, the mine will have a life of at least 31 yr (*25*).

Mount Emmons

The Mount Emmons deposit is in the Elk Mountain mining district, Gunnison County, with coordinates of N38° 52′08″ latitude and W107° 02′19″ longitude. The mineralized area lies just inside the western edge of the Colorado mineral belt, at the juncture of the northwestern border of the belt and the estern edge of the Elk Mountains. Molybdenum mineralization also occurs in a breccia complex that outcrops in the Redwell Basin glacial cirque. Within the basin, protruding outcrops of a mineralized breccia pipe stand about 33 m above the basin floor.

Three major zones of mineralized rock were identified within the Redwell Basin complex: one zone containing the base metals lead, zinc, and copper, and two lower zones related to the rhyolite and granite porphyry stockworks (*28*). The major minerals in the stockworks are molybdenite and cassiterite. Molybdenite occurrences vary from composite veinlets of quartz-molybdenite-pyrite to quartz-molybdenite, to monomineralic molybdenite veinlets as well as disseminated rosettes. Huebnerite generally occurs in veinlets with pyrite and in some places with quartz. Where pyrite-huebnerite veinlets occur with molybdenite-bearing veinlets, the former always cut the latter.

The Mount Emmons molybdenum deposit is about 366 m below the surface in the south slope of Mount Emmons. The ore body forms a series of inverted cuplike shells positioned above the intrusive body. The mineralized shells form concentric patterns with a diameter of about 702 m and an average thickness of about 91 m.

Early mining in the area was for lead-silver-copper ores. The Keystone Mine produced these metals for many years until it was shut down in 1959. The Climax Molybdenum Co. began exploring the area for molybdenum in 1974, and a drilling program was started in 1975.

The size of the ore body was first published in 1977 at 81.7 million mt ore. The current recoverable resource is now estimated at 132.4 million mt with an average grade of 0.258 pct Mo (*25*) at a cutoff grade of 0.12 pct Mo.

Mount Emmons is a well-explored deposit, but development seems still very remote. Aside from the substantial capital investment requirements, environmental problems facing the project present a major obstacle. The major areas of concern are land disturbance (subsidence), flora and fauna disturbance, air and water quality, esthetic qualities, and sound pollution. In addition, the residents of nearby Crested Butte firercely oppose the development. On February 4, 1984, Amax Inc. announced an indefinite delay of the project (*29*).

New Mexico

Questa

The Questa Mine is situated in the Red River mining district of New Mexico, with a latitude of N36°41′50″ and a longitude of W105°29′31″.

The Questa deposit lies on the west side of the Taos Range, a part of the Sangre de Cristo Mountains. The range is underlain by Precambrian rocks and a Tertiary complex (Miocene) of volcanics and intrusives. The granites were the first instrusions into the Precambrian rocks and were followed by an andesite flow overlying the granite. The andesites are capped by a sequence of rhyolite prophyries, tuff, and tuff breccias. Quartz porphyry plugs, consisting of quartz monzonites and granites, intruded the Precambrian rocks. The Tertiary intrusives and volcanics are considered to be the sources of mineralization that occurs principally along the flat-lying contact between the andesite and granite and extends both above and below these contacts. The mineralization is characterized by fracture filling ranging in size from hairline cracks to fissures 0.6 m wide and containing mostly quartz, pyrite, and molybdenite, with conspicuous amounts of fluorite, biotite, and calcite.

The property was first located in 1916. In 1920 Molybdenum Corporation of America (Molycorp) acquired the property and started production. The mine shut down in 1921 owing to weak molybdenum demand. Mining resumed in 1923 at a rate of 45 mt/d from an underground operation and continued until 1956. All production was from high-grade fissure veins. The deposit, selectively mined, provided an average mill feed of about 2.4 pct Mo (*30*).

Under contract with the Defense Mineral Exploration Association, exploration work was undertaken from 1957 to 1960 to determine the feasibility of establishing low-grade surface mining. After the contract expired, Molycorp continued the exploration work. In 1964, sufficient reserves had been blocked out to justify a 9,070 mt/d operation. A high stripping ratio forced the decision to phase out surface mining operations in 1985, the same year that the newly discovered ore body (Goat Hill) is planned to be fully operational. The Goat Hill ore body is to be mined by an underground block-caving method. At the present in situ reserve of 113 million mt, the mines have a life of 20 yr, at an annual capacity of 6 million mt ore (*30*)).

Idaho

Thompson Creek

The Thompson Creek Mine is in a metasomatized quartz monzonite core of the Thompson Creek granodiorite stock. It is located in the Bay Horse mining district of central Idaho (Custer County) between Thompson and Bruno Creeks at an

elevation of 1,890 to 2,680 m. In the mineralized zone are a large number of coarse-grained, quartz biotite, feldspar-muscovite veins and veinlets containing the majority of the molybdenum mineralization. Molybdenite is the sole ore mineral with a gangue of quartz, biotite, muscovite, orthoclase, microcline, sericite, and pyrite. The molybdenite is found as veinlets, stringers, and disseminations in the altered zone. Most of the ore mineralization occurs in quartz-rich veins. Some tungsten is present, but there are no plans for its recovery (*31*).

The deposit was discovered in 1967 by Cyprus Exploration Co. An open pit mine, Thompson Creek began production in 1983. At full capacity, the mine will have an annual production of about 8,051,400 mt ore, containing about 18 million lb Mo (recoverable). At this capacity, the 175.1 million mt ore will last for about 22 yr (*32*).

White Cloud (Boulder Creek)

The property is in the Little Boulder Creek mining district of central Idaho (Custer County). The deposit is within the Sawtooth National Recreation Area in the headwaters of Little Boulder Creek. The elevation of the deposit ranges from 2,600 m to 2,850 m along the southeastern margin of White Cloud Peak.

The White Cloud deposit is a molybdenum stockwork containing molybdenum-rich quartz veinlets in a more intensely fractured zone where mineralization is confined. Minor amounts of mineralization are disseminated throughout the remainder of the rocks (*33*).

The grade of mineralization is relatively uniform on the surface and at depth. The grade decreases away from the intrusive. Molybdenite is the sole ore mineral, with quartz, feldspar, diopside, calcite, hornblende, garnet, epidote, chlorite, biotite, pyrite, and arsenopyrite as gangue minerals. Scheelite is found throughout the deposit, but in amounts too small to consider economically recoverable (*33*).

White Cloud Peak is an area of great scenic beauty, so that any mining-related activity met strong public opposition. This public opposition led to the creation of the Sawtooth National Recreation Area, which imposes severe restrictions on mining activities. Mine development of this property seems a very remote possibility.

Available resource data on the deposit are limited and conflicting. Tonnage estimates range from 90 million to 229 million mt.

Montana

Big Ben

The Big Ben deposit lies in the Little Belt Mountains on the north slope of Poverty Ridge in Cascade County. The deposit is covered mostly by unpatented claims in the Lewis and Clark National Forest. The explored deposit is located at N46°57′51″ latitude and W110°42′43″ longitude.

The Big Ben deposit is a stockwork molybdenum deposit emplaced near the contact of an Eocene hypabyssal alkali granite stock within a Precambrian basement of gneiss and schist (*34*). The stock is composed of four crudely zoned phases, which formed the cupola of an early Tertiary batholith. Emplacement of the batholith as laccolithic intrusions has uplifted the Little Belt Mountains to form a broad east-west anticlinal arch (*35*). It is localized along a 130- to 170-m-wide, east-northeast trending shear near the southern contact of granite porphyry. The shear dips about 50° south and defines a segment of a major fault. Higher grade portions of the deposit appear to result from overlapping of several mineralizing phases (*34*).

Molybdenum mineralization occurs as molybdenite in and along the walls of numerous intersecting quartz veinlets. The most prominent quartz-filled fractures trend north 20° to 80° east and dip steeply north and south. Higher grade mineralization is associated with stronger silicification. Minor chalcopyrite, galena, sphalerite, and fluorite are found in open crystal cavities. Principal gangue minerals are finely disseminated pyrite and quartz (*36*).

The deposit was staked between 1922 and 1940 and explored by two adits (*37*). In 1942, the Bureau of Mines and the U.S. Geological Survey made preliminary examinations of the property as part of the governments strategic minerals investigation program, to locate emergency sources of open-pit molybdenum. The following year, the Bureau completed four diamond drill holes totaling 422 m in depth. In addition, the Bureau channel-sampled the underground workings and performed metallurgical testing of the samples.

The resource used in this availability study for the proposed mine was 107 million mt. The deposit would be mined by open-pit methods at a rate of 15,286 mt/d ore and 41,272 mt/d waste for a life of 20 yr.

Nevada

Tonopah (Hall)

The Tonopah molybdenum mine is located in the San Antone mining district (Nye County) on lands administered by the Bureau of Land Management. The deposit is situated at approximately N38°19′23″ latitude and W117°17′31″ longitude.

The locus of mineralization of the Tonopah deposit is the contact area between the intrusive quartz monzonite stock and the intruded rocks consisting of sericitic quartzite, quartz mica schist, limestone, and tuffaceous limestone. Many narrow veins characterize the contact zone, which constitutes about 30 pct of the rock volume. Sulfides associated with veining are concentrically zoned. Molybdenite mineralization is found in relative abundance, in a ring-shaped band of chalcopyrite farther from the stock; sphalerite and minor galena occur at the fringes of the sulfide depositions (*38*).

In plan view, the ore body is ring shaped with a radius of 635 m from the center of the stock to the center of the molybdenum zone. It has an approximate thickness of 103 m. Sulfide mineralization diminishes outward from the zone for a distance of 660 m or 1,295 m from the center of the stock (*38*).

The pipelike stock is separated vertically into three zones. The upper and the middle zones are exposed in the west and central portion but are covered in the east by a series of volcanic rocks. The upper zone ranges in depth from 0 m on the west to 240 m on the east. One oxidized zone, made up of copper minerals in quartz monzonite, constitutes the copper ore body. The upper zone must be stripped before the molybdenum ore body can be mined. The middle zone, lying immediately below the upper zone, is unoxidized and composed of chalcocite and molybdenite in quartz monzonite; it constitutes the main molybdenum ore body. The lower zone is separated from the middle zone by 120 m of barren rock. Approximately 90 m thick, the lower zone contains molybdenite in quartz monzonite.

The San Antone district was discovered in 1863, and there had been intermittent production of silver, lead, and

gold until 1920 (*39*) when mining ceased. Since then, several companies prospected, explored, and sampled the area, including the Bureau of Mines. Anaconda, which has been exploring the area intermittently for 25 yr, acquired the property in 1955 (*40*)). Serious exploration began in 1975 when three drilling rigs completed 91,440 m of core from approximately 300 holes. Current resources stand at 150 million mt with an average grade of 0.096 pct Mo. At full mining capacity of 7 million mt/yr, the deposit will have a productive life of about 22 yr (*41*).

Buckingham

The Buckingham molybdenum deposit lies in the copper basin area in the northeastern part of the Battle Mountain mining district, Lander County, at an average elevation of 1,770 m. The deposit is located in an area of mixed private and Bureau of Land Management (BLM) administered lands, at an approximate latitude of N40°36′56″ and longitude of W117°03′42″.

The Buckingham deposit is a calc-alkaline, molybdenum stockwork porphyry system with potential credits in silver, gold, tungsten, and copper. Molybdenite was deposited in quartz veins and as fracture coatings. Copper and tungsten appear to form a halo near the outer 0.05 pct MoS_2 and 0.10 pct MoS_2 rock boundaries, respectively. Chalcopyrite occurs in quartz and quartz-molybdenite veins, while the tungsten occurs predominantly in pyrite veins and as fractures which cut molybdenite mineralization.

No reserve-resource data have been published on the Buckingham deposits. Using available data and economic criteria, a resource tonnage of 217 million mt was calculated as a part of this availability evaluation. At a mining capacity of 20,000 mt/d ore, the mine would have a life of about 31 yr.

B&C Springs

The B&C Springs deposit is in the Paradise Peak mining district, Nye County. It is situated on lands administered by both the BLM and the U.S. Forest Service. The deposit has a latitude of N38°46′50″ and longitude of W117°48′06″.

The deposit was first detected by an airborne magnetometer and induced polarization surveys, flow in 1968. A diamond drilling program in the area was initiated in 1969, when a nearly horizontal ore zone containing 0.030 to 0.075 pct Mo was confirmed.

The irregular ore bodies are interlayered and interbedded and appear concentrated within fractured carbonates. Molybdenite and chalcopyrite are the major ore minerals. The accessory sulfide minerals are pyrite, tetrahedrite, sphalerite, and covellite. The gangue minerals are predominantly calcite, dolomite, quartz and some magnetite.

Proposed mining and beneficiation proposals are based on 33,641,000 mt of demonstrated resources. At the proposed production rate of 6,282 mt/d, which include 943 mt of dilution, the deposit will have a mine life of about 18 yr.

Mount Hope

The Mount Hope molybdenum deposit is located on the southeast side of Mount Hope in Eureka County, in T22N, R21 and 52E. The deposit lies between the southern ends of the Roberts Mountains and the Sulphur Spring Range.

Except for a few patented claims in the central part of the deposit, both surface and mineral rights of the property are managed by the Bureau of Land Management. Exxon Mineral Co., which has a lease-option on the patented claims, applied to purchase about 10,000 acres of Federal land in the general area to construct and operate the mine and processing plants.

The Mount Hope area was discovered in 1870 and opened in 1886 for lead and zinc. Other compaines worked the area including Universal Exploration Co., which operated the mine for lead, cadmium, and silver from 1943 to 1947. Exxon began exploring the area for copper in 1978; however, in 1981, Exxon declared the area had potential for molybdenum instead of copper.

Initial results of exploration indicated an inferred reserve of 408.2 million mt with a grade of 0.078 to 0.192 pct Mo (*42*).

If the inferred resource is brought to the demonstrated level in the future, Exxon proposes to mine the deposit by open-pit method at a daily capacity of 27,210 mt ore and about 68,000 mt waste. Based on this capacity, the deposit is estimated to have a minimum productive life of 41 yr. The capital investment to develop the deposit was estimated in 1983 at $600 million (*43*).

Washington

Mount Tolman

The Mount Tolman deposit lies on the Colville Indian Reservation, Ferry County. This explored deposit is located at N48°03′20″ latitude and W118°43′35″ longtitude in north-central Washington. The topography is mountainous with moderate to steep slopes, with elevation rising from 390 m at the San Poil arm of Lake Roosevelt to 1,080 m at Mount Tolman, 2 km to the west.

Mount Tolman is a hydrothermal quartz stockwork copper-molybdenum deposit. Ore occurs mostly within a 610-m-thick, intense quartz stockwork zone in the Mount Tolman granodiorite phase of the pluton. Post-ore dikes form an interval of waste and increase in density to the east, eventually eliminating ore (*44*).

The mineralized zone is steep-faulted down to the east and north by a series of northeast-and northwest-trending normal fault systems. Primary ore minerals are molybdenite and chalcopyrite. Molybdenite occurs in quartz fracture fillings and less commonly in replacement veins of quartz sericite and pyrite. Chalcopyrite and some galena and sphalerite occur as discrete grains scattered irregularly within the replacement veins of quartz sericite and pyrite. Associated magnetite is also present (*44*).

The deposit is approximately 1.6 km wide, 3.2 km long, and 370 m thick, with a central zone containing greater than 0.12 pct MoS_2 (*44*).

No production has been recorded from the numerous small prospects located near Mount Tolman. In 1953, Bear Creek Mining Co., an exploration subsidiary of Kennecott Copper Co., began examining the area in detail. In 1964, a permit from Colville Tribes was acquired to explore and evaluate approximately 20,000 acres. Upon expiration of the exploration permit, no new lease was signed. In the spring of 1978, the Tribal Business Council solicited competitive bids from interested mining companies. Amax Inc. was selected and a 3-yr exploration agreement was signed on August 8, 1978.

Based on the 91,140 m of diamond drilling, the prospect has an estimated resource of 900 million mt ore, with a grade of 0.09 pct Cu and 0.06 pct Mo using a cutoff grade of 0.05 pct Mo (*45*). In 1982, Amax Inc. abandoned the property (*46*).

CANADA

British Columbia

Endako

The Endako Mine, the largest primary molybdenum producer in Canada, is located in central British Columbia at a latitude of N54°02′00″ and a longitude of W125°07′00″. The crest of the open-pit mine has an elevation of 1,070 m.

The Endako deposit is within the interior system of the Canadian Cordillera in the Nechako Plateau (*47*). The deposit occurs in the Endako Quartz Monzonite, which is one of the rock types of the Composite Topley Intrusion that are intruded into late Paleozoic and early Mesozoic sedimentary and volcanic rocks.

The ore body is an elongated elliptical stockwork measuring 3,360 m long and 370 m wide. The east half of the ore body, where the open pit has been developed, has a depth of 370 m over a length of 1,830 m. The west half of the ore body attains a maximum depth of 150 m, adjacent to the West Basalt Fault. It is characterized by intense fracturing and veining.

The most abundant primary minerals are molybdenite, pyrite, and magnetite with minor amounts of chalcopyrite and traces of bornite, bismuthinite, scheelite, and specularite. Ore minerals occur in two types of veins: in large quartz-molybdenite veins and in fine fracture fillings and veinlets in the form of a stockwork.

The molybdenite deposit was discovered and staked in 1927, but exploration work was sporadic until 1962 when a diamond drilling program was initiated by R and P Metals Corp. Ltd. Endako Mines was incorporated in October 1962, at the same time when Canadian Exploration Ltd. (a subsidiary of Placer Development Ltd.) entered into an exploration agreement. Following a positive evaluation, as a result of the diamond drilling program and underground sampling, a decision to develop the property was announced in March 1964 (*47*). The present demonstrated resources are estimated at 195 million mt ore.

The open pit operation has an annual production of about 10,320,000 mt ore. The ore is processed in a standard crush-grind-float concentrator. The final concentrate is transferred to the roasting facility located adjacent to the mill for conversion to MoO_3.

Boss Mountain

The molybdenum deposit is near the headwaters of Molybdenum Creek on the northeast slope of Takomkane Mountain. The deposit is north-northeast of Vancouver, BC, with location coordinates of N52°06′00″ latitude and W120°56′00″ longitude (*48*).

The Boss Mountain deposit is part of the Quesnel Trough containing breccia pipe bodies about 335 m in depth, 60 to 120 m in length, and 9 to 30 m in width. Molybdenite-rich quartz veins surround the upper breccias.

Molybdenite mineralization occurs in three different forms: (1) as disseminated fine grain mineralization within the quartz matrix of the breccia pipes, (2) as coarse-or fine-grained layers in quartz stringers, and (3) as a fine-grained film or paint along fractures, joints, and shear planes.

Molybdenite was first discovered on Takomkane Mountain in 1917, and in the fall of that year several hundred kilograms of molybdenite ore were shipped to Ottawa. In 1930, several hand trenches were excavated on one of the larger quartz-molybdenite veins and on a molybdenite-bearing breccia. Sporadic exploration work was done in the area until 1955 when the claims were acquired by H.H. Heustis. In 1956, Climax Molybdenum Co. Ltd. optioned the claims and completed over 1,000 m of diamond drilling before terminating the option in 1960.

Noranda optioned the property in 1961. After 4 yr of exploration and development work, production was started in 1965 at a mill rate of 900 mt/d. Production continued until 1972, when the mine was closed because of the depressed molybdenum market. The mine was reopened in early 1974.

The ore deposit has been mined by both underground open stope and open-pit operations. The current remaining demonstrated reserve is calculated at 4.9 million mt ore. With a production rate of 1,832 mt/d from underground and 1,466 mt/d from open-pit operations, the current reserve will maintain a productive life of about 6 yr (*49*).

Ores from the mine are treated in a single-product flotation concentrator. Molybdenite concentrate is the final marketable product. The concentrate is packaged and transported to Vancouver.

Kitsault

The Kitsault molybdenum deposit is located in northern British Columbia, near the Alaskan border. The mine is located 7 km southeast of the town of Kitsault with location coordinates of N55°25′00″ latitude and W129°25′00″ longitude. The deposit lies within the rugged mountain cost ranges, with an elevation of about 610 m.

The Kitsault deposit is an intrusive complex composed of at least five separate stocks and related dikes. The first three intrusives were essentially barren of sulfide mineralization. The last two intrusives were composed of more differentiated magmas and supplied the source for molybdenite and other sulfides (*50*).

The Kitsault property was first placed into production by British Columbia Molybdenum Ltd. a subsidiary of Kennecott Copper Corp., in the late 1967. The open pit and mill were designed to operate at a rate of 5, 440 mt/d. The operation was shut down in mid-1972 because of a depressed market.

AMAX Inc. purchased the Kitsault property from Kennecott in late 1972 and reopened the mine at an expanded capacity. Reconstruction started in May 1979 and production in January 1982. Due to market conditions, the mine again was closed in October 1982 and remains closed indefinitely.

The Kitsault deposit was mined by an open pit operation with a design capacity of 10,886 mt/d ore. The overall stripping ratio is 1.86 to 1.00. The current demonstrated resource is estimated at 104.3 million mt (*25*).

Ore from the mine was processed in the Kitsault concentrator by crushing, grinding, and single-product flotation. Molybdenite concentrate was packaged and transported to Vancouver, BC.

Glacier Gulch

The Glacier Gulch molybdenum deposit is located on the east flank of Hudson Bay Mountain, a glaciated pile of Mesozoic rocks near Smithers, BC. The deposit coordinates are N54°49′00″ latitude and W127°18′00″ longitude, with an exploration adit driven at an elevation of about 1,066 m.

The oldest and most widespread lithologic unit exposed on the Hudson Bay Mountain is the Hazelton Group,

characterized by a thick sequence of poorly layered volcanic and sedimentary rock of Jurassic age. In the mineralized area, only volcanic members of the Hazelton Group are present (*51*).

The occurrence of numerous small concentric mineral zones is the main geologic feature of Hudson Bay Mountain. The Central zone is defined by the Glacier Gulch Mo-W-Cu mineralization. Molybdenite mineralization is confined in fracture veins and veinlets, except for minor disseminated occurrences in the quartz-monzonite stock immediately beneath a rhyolite plug (*51*).

William Yorke-Hardy and Associates first staked several claims over some of the molybdenite-bearing veins in Glacier Gulch in 1956. Later the claims were optioned and explored by various groups within AMAX Inc. In 1971, Climax Molybdenum Corp. Ltd. (an AMAX Inc. subsidiary) purchased the property. An exploration program consisting of 3,000 m drifting and 53,900 m of core drilling has defined a deposit that could become an economic source of molybdenum in the future. The delineated resource is estimated at 18 million mt grading 0.21 pct Mo.

Ajax

The Ajax deposit is located in the Skeena mining district in British Columbia. The claims lie approximately 13 km northeast of Alice Arm with location coordinates of N55°35′00″ and W129°24′00″.

The eastern flank of an anticlined structure is the locus of a belt of small intrusive bodies of Tertiary age, which are composed of quartz monzonite porphyry, quartz-diorite porphyry, granodiorite, and associated intrusive rock types with which molybdenite is associated (*51*). The surface exposures of these intrusives show an elliptical shape measuring approximately 915 by 762 m, with the long axis oriented to the northwest.

Molybdenite mineralization is associated with secondary quartz and occurs in quartz veinlets in hair line fractures, as stringy lenses with pyrrhotite, or as coatings along fracture surfaces. Minor amounts of molybdenite are also found in disseminated form associated with interlocking quartz and pyrorhtite within the highly siliceous and sericitized section of the porphyry. The majority of the molybdenite is found within the fine quartz veins with molybdenite concentrated along contact boundaries of the veinlets (*52*).

Properties peripheral to the molybdenite zone were first prospected for lead-zinc-silver in the early part of the century. The presence of molybdenite mineralization reported in the 1927 Minister of Mines' Annual Report, prompted S.J. Barclay in 1965 to locate property for Newmont Mines Ltd. Drilling and underground exploration work done between 1965 and 1967 indicated that the molybdenum mineralization zones are lens-like in form and extremely erratic in lateral and vertical extent. This prospect has a resource estimate of 418.4 million mt using 0.036 pct Mo as a cutoff grade.

Adanac

The Adanac deposit is located within the Atlin mining district in the extreme northeast portion of British Columbia, near the head of Ruby Creek Valley. The location coordinates are N59°42′30″ and W133°24′00″. The deposit lies at an elevation of 1,463 m in an open alpine valley.

The deposit is situated within the northern edge of Mount Leonard Boss, and is divided by the Adera Fault into a northern area (*53*). Six major and several minor rock units were identified in the vicinity of the deposit.

Veins occur in all major rock types, but are most common in the coarse granite, crowded porphyry, and porphyritic granite. The Adanac deposit is approximately 1,036 m long and 550 m thick. Molybdenite mineralization extends beyound these dimensions but in small amounts (*54*).

The discovery claims on the Adanac deposit were staked by Adanac Mining and Exploration Ltd. in 1967. During 1968, Adanac Mining commenced an exploration program that included a geochemical survey and diamond drilling totaling 1,502 m from 12 holes. In 1969, a total of 11,273 m of diamond drilling was completed from 68 holes. Kerr Addison Mines Ltd. optioned the property in 1970 and carried out an extensive exploration program. At the end of 1971, the exploration program accomplished 19,812 m of diamond drilling, 1,219 m of rotary drilling, and 823 m of underground development including bulk sampling, pilot mill tests, and a full-scale feasibility study of the property.

From 1972 to 1978, exploration was again conducted on the property by Adanac Mining, Noranda Mines Ltd., and Climax Molybdenum Corp. (BC) Ltd. In December 1978, Placer Development Ltd. and Adanac Mining and Exploration Ltd. reached an agreement to develop the deposit. In 1979, Placer conducted additional exploration work. Placer terminated the option agreement in January 1983, because of the depressed market.

The current minable ore reserve is estimated at 201 million mt at an average grade of 0.059 pct Mo. The ore will be mined by conventional open-pit method, with an overall stripping ratio of 1.56 to 1.00 (*54*).

Red Bird

The Red Bird property consists of 239 claims in west-central British Columbia about 160 km south of Smithers. The deposit is situated on the eastern edge of the rugged Coast Range Mountain, immediately outside the west boundary of Tweede Mine Park and the Eutsuk Nature Conservancy. The location coordinates are N53°18′00″ and W127°01′00″.

The deposit consists of three zones which are located within a peripheral ring around the main mass of a quartz monzonite porphyry pluton. This pluton is roughly elliptical in shape, measuring about 1,200 m north-south and 800 m east-west.

The mineralized zones occur at or near the volcanic porphyry contact and peripheral to the contact. Mineralization is restricted to the quartz monzonite porphyry. However, exceptions do occur, especially in the southwest zone, where molybdenite values in excess of 0.12 pct Mo are present in volcanic rocks. Quartz veining, with which the molybdenite mineralization is associated, is most abundant within about 45 m of the volcanic-porphyry contact. The intensity of veining tends to decrease rapidly away from the pluton.

The claim on the property was first staked in 1959 by Phelps Dodge Corp. personnel. The claim group was enlarged in the following years. Major exploration work on the property, which included mapping, trenching, geophysical surveys, and diamond drilling, was conducted from 1963 to 1967. During that time, 17,350 m were drilled from 70 holes.

In 1979, Craigmont Mines Ltd. optioned the property, and additional exploration work was done on the deposit (*56*). From 1979 to 1980, Craigmont completed approximately 14,000 m of diamond drilling from 53 holes. Craigmont dropped the option agreement in 1981 due to the declining molybdenum market.

Although mineable resources are currently not yet fully established, they are estimated at approximately 100 million mt ore. This prospect would be mined using a conventional open-pit method.

Mount Thomlinson

The Mount Thomlinson deposit is located 38 km northeast of Hazelton, BC, with location coordinates of N55°35′00″ and W127°29′00″.

Molybdenum mineralization occurs along the northwestern contact of stock cutting argillites of the Bowser Lake Group. The concentration of molybdenite and chalcopyrite are found in a quartz vein system along the northwestern border of the stock.

Molybdenite, pyrite, and a lesser amount of chalcopyrite occur in altered, sheared, and fractured biotite granite and in a tabular stockwork zone up to 100 m wide along the northwest contact of the stock. The mineralized zone is characterized by abundant leucogranite and felsite dikes that are crosscut by the stockwork. The richest molybdenite mineralization is most intimately associated with intense argillitic alteration. Pyrite content commonly reaches 2 to 3 pct in the mineralized intervals. It is generally associated with molybdenite or chalcopyrite.

Molybdenum showings in the area were originally staked in 1962, and in 1963 the property was optioned, mapped, trenched, and sampled by Butte Lake Mining Co. Ltd. In 1963, the property was examined and later optioned by Southwest Potash Corp., a subsidiary of AMAX Inc. The following year, Southwest Potash Corp. conducted exploration work including mapping, surveying, and drilling of 1,377 m from five holes. A resource of 1.8 million mt ore grading 0.108 pct Mo, centered in the southern end of the mineralized zone, was determined. In 1965, exploration was directed toward the evaluation of the northern part of the mineralized zone. The option was terminated in 1965, because the grade was considered too low.

The published ore resource figure for the Mount Thomlinson deposit is 40.8 million mt grading 0.07 pct Mo (*57*).

Trout Lake

The Trout Lake molybdenum deposit is in southeastern British Columbia, about 3 km from Trout Lake Village. The location coordinates for the Trout Lake deposit are N50°38′00″ and W117°36′00″. The Selkirk Mountains, where the deposit is located, have an elevation ranging from 700 to 2,700 m.

The molybdenum deposit is situated at the north end of the Kootenay Arc, which is a bow-shaped formation characterized by a belt of highly deformed, heterogeneous sedimentary rocks.

The Trout Lake molybdenite stockwork deposit is one of a series of calc-alkaline stocks located in the Kootenay-Upper Arrow Lake area. Molybdenum mineralization is associated with several of these calc-alkaline stocks.

Molybdenite mineralization occurs over a vertical range of more than 1,000 m in two zones: the upper, smaller "A" zone, which outcrops; and the larger, irregular, vertically attenuated "B" zone, which is up to 300 by 200 m wide as defined by the 0.060 pct Mo contour. Molybdenite, as fine to medium flakes and rosettes accompanied by pyrite and pyrrhotite, is mainly present along the margins of veins in a quartz stockwork. Occasionally, in higher grade zones (in excess of 0.06 pct Mo), the molybdenite is strongly disseminated in microfractured intrusive bodies up to 20 m wide by 200 m long, accompanied by large veins and intense quartz flooding. The major control of molybdenum grades is the location of the schist intrusive contact; a lesser control is exerted by premineral faults (*58*).

Geologic ore resources, as indicated by drilling, are currently estimated at 48.7 million mt grading 0.115 pct Mo, within which there are several zones of higher grade material. Although the ore body is open at depth, no drilling has been done at the lower levels of the deposit.

The proposed mining method for the Trout Lake deposit is underground blasthole open stoping with delayed cemented backfill. At present, the ore body is accessed by an adit extending 1,372 m through waste rock and 610 m across the ore body at its approximate midpoint.

MEXICO

Sonora

Cumobabi

The Cumobabi ore deposits (San Judas, Transvaal, Transvaal West, and Molibdeno) lie on the southern end of the great southwest U.S. Copper-Molybdenum Province in La Verde mining district in the State of Sonora. The approximate coordinates are N29°50′00″ and W109°58′00″. The mine is situated in a rugged terrain with peaks rising 1,700 m above sealevel.

About 60 pct of the Cumobabi area is covered by volcanic rock. The volcanic sequence has been intruded by a body of predominantly acidic nature and is sometimes covered by rhyolite outflows (*59*). Strong tectonic activity took place following the intrusion which formed the breccia ore bodies (San Judas, Transvaal Breccia, Transvaal West, and Molibdeno).

The San Judas ore body is 70 m wide, 300 m deep, and 300 m along strike. Mineralization is found in the upper level of the ore body which is dome-shaped and has clearly defined the lower limit.

The Transvaal Breccia ore body contains high copper values and some silver. This intensely fractured ore body is somewhat smaller than the San Judas, measuring 200 m in length, 50 m in width, and 450 m in known depth.

The Transvaal West is a contact breccia consisting of a silicified, intensely fractured zone. Molybdenite mineralization is essentially associated with quartz and orthoclase.

The Molibdeno Breccia resembles the Transvaal in that it contains high copper values in the upper layer. The central portion contains the highest molybdenum values. The mineralized body has the form of an inverted cone, with the base measuring 170 m by 120 m and the apex at a depth of 300 m.

Small-scale mining has been recorded in the Cumobabi area since the late 1800's. In 1966, Minera Hermosillo S.A. acquired several claims in the area and conducted diamond drilling and underground exploration which continued through 1970. In 1978, Minera Cumobabi S. A. de C.V. acquired the claims including the San Judas breccia, which was developed and mined (*59*).

The present composite proven ore reserves, which includes the extension of San Judas-Transvaal porphyry and the two Transvaal breccias, are estimated at 17.15 million mt. A large inferred resource is believed to be present, but sufficient drilling has not yet been conducted to accurately establish the total resources.

The first ore body mined was the San Judas, by conven-

tional open-pit method. The pit was designed to handle a capacity of 4,300 mt of ore and waste.

Opodepe

The Opodepe deposit is about 70 km northeast of Hermosillo, the capital city of the State of Sonora. The location coordinates for the deposit are N29°29′00″ and W110°39′00″ at an elevation of approximately 1,000 m above sea level.

Mineralization of economic interest at Opodepe consists mainly of molydbenite and secondary copper mineralization located on the southern flanks of Creston Hill. Accessory metallic minerals such as galena, sphalerite, and chalcopyrite were observed, but these minor occurrences are of no economic importance. Most of the molybdenum mineralization occurs as fine-to coarse-grained (0.1-to 3.0-mm) crystals. The main host rock is the Creston Granite, which makes up the bulk (+70 pct) of the Creston stockwork molybdenum deposit as presently known.

Over 20 pct of the mineralization is in the quartz matrix. Here the molybdenite occurs in fine-grained flakes (0.05 to 1 mm), at the very contact of the quartz matrix with the breccia fragment. The remaining molybdenite occurs as coarsely disseminated rosettes in short zones of massive coarse-grained sericite. This type of molybdenite occurrence is commonly found in Creston Granite (*60*).

Exploration work in the area was carried on intermittently from the 1920's until 1959, when Ciá Minera Penoles blanketed the area with mining claims. Several other companies conducted exploration work in same area, but later withdrew. In 1974, AMAX Inc. decided to negotiate an exploration contract and initiated an exploration program which included geological mapping and geochemistry, followed by diamond drilling. A total of 40 holes were drilled between 1974 and 1979. Ciá Minera Fresnillo S.A. de C.V. assumed management of the property in 1981.

An indicated geologic resource was estimated at 180 million mt grading 0.09 pct Mo. Owing to limited exploration work, the full potential of the deposit is not yet determined. The property can probably be mined as a conventional open-pit operation.

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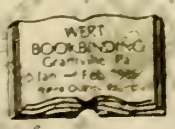

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